THE STUDENT'S HUMAN PHYSIOLOGY

ERNEST EVANS

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STUDENT'S HUMAN PHYSIOLOGY

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THE STUDENT'S HUMAN PHYSIOLOGY

A FIRST YEAR'S COURSE IN THE PRACTICE AND THEORY OF THE SUBJECT

BY

ERNEST EVANS

NATURAL SCIENCE MASTER, TECHNICAL INSTITUTE, BURNLEY

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PREFACE

In nearly every published report which deals with the condition of the people there is one outstanding feature, viz. the lamentable lack among the people of the knowledge of the working of the human body, and of the Laws of Health. It is also generally recognised among experts that the consequent physical degeneracy, which arises from the ignorance of health matters, might be prevented if the people were given an adequate education in Human Physiology and Hygiene. At present, in schools and colleges of all descriptions, little is being done in the way of bringing within the reach of the mass of the people a knowledge of the elementary principles which underlie Health Science. In fact, there is an actual decrease in the teaching of Human Physiology and Hygiene in evening continuation schools, secondary schools, and evening technical schools. If the future race is to grow up strong, with a sound mind in a sound body, it is time to introduce into the regular school course the study of Human Physiology and Hygiene.

Educational experts have said that there are many difficulties in the way of introducing the subject of Human Physiology into schools, for the school course

is already crowded with subjects, and there is the difficulty of arranging a workable scheme which would give good lasting results to the pupils.

This book has been prepared with the object of showing how a complete course of instruction in the practice and theory of the more elementary parts of Human Physiology can be given, and it contains all the essentials of a first year's course in the subject. The study is not costly, and the book shows how it can be done with the minimum expense for apparatus and materials. In addition, many of the objections which have been advanced against its introduction into schools have been removed by the arrangement of the experiments. From an educational point of view it can be made just as profitable as the study of any other branch of science, and the knowledge gained by the pupils will be of lasting benefit throughout life.

The arrangement of the practical part of the work is the result of the experience gained during many years in teaching large and successful classes in Human Physiology, and the experiments have been chosen so as to be within the reach of a first year's student.

Messrs. Flatters, Milborne & M'Kechnie have kindly allowed me to use some of their photomicrographs, and in return I recommend their microscopic slides to the readers of this book. The new figures in the book have been drawn by Mr. W. E. Holt and Mr. George Hewes from my own preparations, and my acknow-

ledgments are due to them for the careful way in which the drawings were made.

In the corrections of proofs I have been assisted by my former students, Mr. A. R. Kenyon and Mr. E. R. Pilling, while Mr. Holt has kindly read through the proofs. To all those who have aided me during the preparation of the book I offer my grateful acknowledgments.

ERNEST EVANS.

TECHNICAL INSTITUTE,
BURNLEY.

CONTENTS

ILLUSTRATIONS

THE
STUDENT'S HUMAN PHYSIOLOGY

CHAPTER I

INTRODUCTION

HUMAN PHYSIOLOGY.—The division of **Biology** which treats of the structure and functions of the normal human body is known as **Human Physiology.** Its object is to answer all questions concerning the structure and working of the various parts of the body during health, leaving the problems which arise from a diseased condition of the body for Medical Science to solve. It calls to its aid the discoveries made by chemists and physicists in solving many of the important problems of the science, and expects much from the modern study of Biochemistry.

Physiology originated in the golden age of Greece, and Hippocrates can be considered to be the father of Medicine and Physiology; while Herophilus ascribed the pulse to the contraction of the heart, and traced out nerves, glands, lacteals, and tendons. The school of medicine founded by Herophilus was famous for many centuries. After the fall of ancient Greece, the knowledge of Physiology was kept alive in Persia by the Persians, and in Europe by the Arabs, who made numerous discoveries in all departments of knowledge.

The modern science of Physiology was established in

the sixteenth century by Harvey when he discovered the circulation of the blood. Harvey was a brilliant medical practitioner and a man of science, a combination somewhat rare for the sixteenth century, but which has become a common characteristic of the medical profession.

During the seventeenth century the researches of Malpighi in connection with the skin, tongue, alimentary canal, and his discovery that capillaries connected arteries to veins placed the study on a firm basis. Swammerdam discovered blood-heat, and registered it with a new thermometer.

Boerhaave early in the eighteenth century analysed blood, bile, chyle, and lymph, and traced their constituents to the food. Haller made the important discovery of the contractibility of the muscles. The nineteenth century was a most fruitful period, for, among other discoveries, Muller solved the problem of seeing and hearing, and Bernard, by a wonderful series of experiments, made out the functions of the spinal cord, liver, pancreas and salivary glands. These discoveries along with the work done by a host of workers have made Physiology a most progressive science. The twentieth century bids fair to outrival the nineteenth century, for living physiologists are engaged in extending the boundary line of our knowledge of the action of the body. Physiologists have been and still are benefactors to the human race, and the present condition of Medical Science owes much to their labour and discoveries.

THE IMPORTANCE OF HUMAN PHYSIOLOGY IN EVERYDAY LIFE.—It is of importance that every boy and girl should know some little of the wonderful structure and functions of the body, and how to use

this knowledge in everyday life. At present this is largely left to chance, and in only a few cases is an adequate education given in the elements of the subject. If the future race is to grow up strong, with a sound mind in a sound body, it is time we set our house in order, and introduced into the regular school course the study of Human Physiology. The study is not costly, and the following pages will show how it can be done at the minimum of expense for apparatus and material. In addition, many of the objections which are usually advanced against its introduction into schools have been removed in the arrangements of the experiments, and it is just as easy to conduct classes in the practice and theory of the subject as, say, in chemistry or physics. From an educational point of view it can be made just as profitable as the study of any other branch of science, and will be of lasting value throughout life.

A sound knowledge of the elements of Human Physiology will enable the average person to understand the phenomena which the human body exhibits, and prevent serious mistakes being made in diet, exercise, sleeping, clothing, &c.

THE BODY.—The human body, like every other living thing, is made up of cells, and these are specialised for different kinds of work. The study of cellular structure is known as **Histology**, and a sound knowledge of the working of the body can only be obtained through an elementary acquaintance with the structure of cells.

THE STRUCTURE OF THE ANIMAL CELL.—The animal cell differs from the plant cell in being without a cell-wall, and it is generally united to other

cells with a little cement substance. It varies in size from the $\frac{1}{300}$ to the $\frac{1}{4000}$ part of an inch in diameter, and consists of a **nucleus,** which is surrounded with **protoplasm.** The nucleus is separated from the protoplasm by a thin membrane which is known as the **nuclear membrane,** and a series of fibrils cross it in all directions; these are composed of **linin,** which encloses a beaded substance—the **chromatin**; while the

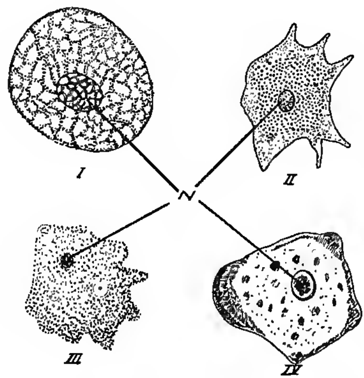

FIG. 1.—*I*, Diagram of animal cell; *II*, an amœba; *III*, a colourless blood corpuscle; *IV*, an epithelial cell from interior of mouth; *N*, nuclei.

interspaces contain the **nuclear sap.** One or more denser particles may be embedded in the nucleus; these are known as **nucleoli.** The protoplasm, which has been termed the basis of life, is made up of proteins, water, and salts. Its exact composition is unknown, but on analysis it gives the elements carbon, hydrogen, oxygen, nitrogen, sulphur, and mineral salts. It seems probable that there is a difference between living and dead protoplasm. If this is so, the killing of it during analysis will prevent the discovery of the

real combination of the above elements. Protoplasm is the most wonderful matter in the universe, for there is associated with it the phenomenon of life, and living beings are far more interesting than dead materials. If it is examined with a suitable microscope, small fibrils cross in all directions, and the interspaces between these contain a fluid. It is of the nature of jelly, and in the cells of some plants it may be seen in motion. At one time or another protoplasm contains all the substances found in the body, and in it constant change is always proceeding. The cells form a laboratory in which we have the building up and breaking down of substances, and they are specialised for special work. The cells in the brain have to do with thought, &c., while those in the skin protect the deeper portions of the body from injury.

TISSUES.—The cells show specialisation of function, and because of this there arises **division of labour** among the units which form the human body. Cells are united to other cells with cement substance, and these form **tissues**. The elementary tissues can be separated into a number of divisions. These are:—

(1) The **connective tissues**, which form the framework of all parts of the body, such as bone, cartilage, and areolar tissue.

(2) The **epithelial tissues**, which generally consist of numerous cells united together with cement, and which line the cavities or cover the surface of the body, such as the epidermis and mucous membrane.

(3) The **muscular tissues**, which produce the movements of bones, heart, and food canal. There are three kinds of muscular tissue, viz. plain, cardiac, and striped.

(4) The **nervous tissues,** from which the brain, spinal cord, and nerves are formed.

HUMAN PHYSIOLOGY A PRACTICAL SUBJECT.—All the natural sciences lend themselves for study in a practical manner, and Human Physiology is no exception to the rule; for the dissection of the various parts of animals which can be obtained from a butcher will throw much light on the structure of the human body. The fluids of the body, such as blood, lymph, bile, and urine, can be examined with very simple apparatus and re-agents. A list of the re-agents and stains required for the study of a first year's course of Human Physiology is given, with a description of their uses.

THE COMPOUND MICROSCOPE.—It is very desirable for the study of blood, milk, lymph, tissues, urine, and food that a compound microscope should be available, but much can be done without the use of such an instrument. The compound microscope should have a 1-inch and $\frac{1}{6}$-inch objectives, and two eye-pieces which will give magnifications from 50 to 500 diameters. The stand must be firm, heavy, and strong. The mirror should have one side plain and the other concave; this is fixed beneath the stage, and it is used for the reflection of the light through the objective and eye-piece. An iris-diaphragm is fixed to the stage for regulating the amount of light which passes through the lenses. The eye-piece and objective are fixed in a tube which can be moved upwards and downwards by means of a rack and pinion, and the fine adjustment will move the objective either a little nearer or away from the object, thus giving better definition.

It is a good plan to examine the objectives and eye-pieces to see if they give a good flat field. This can be done by examining a good prepared slide of blood, and if the corpuscles are seen clearly in all parts of the field without altering the focus, the lenses possess a flat field with good definition. It is also desirable to have a dust-proof nose-piece to carry the objectives, and a box for packing the microscope in. Such an instrument can be obtained from a good dealer for from £5 to £7, but good second-hand ones can be obtained at about half this price.

HOW TO USE THE MICROSCOPE.—The student should use the microscope, and so become familiar with the structure and working of the instrument. The following rules will aid the student:—

(1) Fix the objective and eye-piece in the tube, and with the mirror reflect the light through the lenses until the whole of the field is brightly illuminated. The iris-diaphragm can now be used to regulate the amount of light which enters the objective. With the $\frac{1}{6}$-inch objective a pencil of light will give the best definition.

(2) The prepared slide should be placed on the stage and held in position by the clips. It should always be examined first with the low power (1 inch), and if necessary afterwards with the high power ($\frac{1}{6}$ inch). To obtain a higher magnification change the eye-piece, or pull out the draw-tube.

(3) In focusing the object, the tube should be racked downwards until the 1-inch objective is about 1 inch from the object, then look through the eye-piece, and rack away until the focus is found. This is even more important with the high power, for the tube should be moved until the objective nearly touches the slide,

when the focus can be found in a similar manner to that given above for the low power.

(4) Always learn to use either eye in examining objects with the microscope, and never shut one eye while looking down the tube; with practice it will be possible to see both the object and the point of a pencil used in drawing at the same time.

(5) To increase the magnification, pull out the draw-tube to the third mark, and re-focus. To find the increase of magnification, consult the card which is generally fixed inside the microscope box.

(6) If any mounting fluid, such as water, salt solution, or acid, is spilt on the stage, or finds its way on to the objective, clean it off at once.

(7) Clean the microscope before placing in the box.

(8) Do not unscrew the separated parts of the objective to clean them, for this may introduce dust in between the lenses. If dust is present on the outer lens, it can be removed with a piece of soft wash-leather.

INSTRUCTIONS FOR THE PREPARATION OF COMMON RE-AGENTS, STAINS, ETC.—The following instructions will enable the student to prepare some of the more common re-agents, stains, and mounting fluids used in practical human physiology.

ACETIC ACID.—Mix 1 part of glacial acetic acid with 99 parts of water; this forms a 1 per cent. solution of acetic acid. Cells treated with this re-agent have their nuclei well defined, and it will dissolve the framework of the red corpuscles.

ALCOHOL.—Good methylated spirits should be kept in stock, and a most suitable strength is 92 per cent.

This can be diluted with water to give the required strength for preserving parts of animals, &c.

AMMONIUM SOLUTION.—A saturated solution is used along with strong nitric acid as a test for proteins.

CAUSTIC POTASH SOLUTION.—Weigh out 40 parts of caustic potash, and dissolve in 60 parts of water. This is used for dissolving the cement between muscle fibres, &c.

EOSIN.—Mix 1 part of powdered eosin with 150 of water, or the same quantity in methylated spirits. It will stain the colouring matter in the red corpuscles, and can be used along with methylene blue for double staining.

FEHLING'S SOLUTION.—This can be made by mixing equal parts of the following solutions:—

1.	Copper sulphate	35 parts.
	Water	333 „
2.	Caustic soda	50 „
	Water	333 „
3.	Potassium sodic-tartrate . . .	106 „
	Water	333 „

It is used as a test for grape, invert, and malt sugars. On boiling with it they give a red precipitate. The solutions should be kept in well-stoppered bottles; do not mix more than will be required, for the full solution will not keep in perfect condition.

GLYCERINE.—This can be used as obtained from the chemist, or may be diluted with an equal quantity of water. It is used as a mounting media for either fresh or preserved tissues.

HYDROCHLORIC ACID.—Mix 1 part of strong acid with 10 parts of water. It is used for the removal of lime salts from bone. To decalcify a long bone,

place it in a 10 per cent. solution of common salt to which 2 parts of hydrochloric acid have been added.

Iodine Solution.—This is best prepared by dissolving 1 part of iodide of potassium in 50 parts of water, adding flakes of iodine until the solution is saturated. Then dilute with water until the colour of sherry is obtained. This solution stains cellulose yellow, starch blue, and glycogen a port wine colour.

Methylene Blue.—Dissolve 1 part of methylene blue in 15 parts of methylated spirits. Add to the stain 50 parts of a dilute solution of potash (1 in about 10,000 of water). It will stain the granules in the colourless corpuscles of the blood, and is used as a double stain along with eosin.

Millon's Solution.—This is best obtained from a dealer, and should be kept in the dark. It is used as a test for albuminoids, which give a faint red colour on boiling with this solution.

Nitric Acid.—Strong nitric acid is used along with a saturated solution of ammonia as a test for proteins.

Osmic Acid.—A 1 per cent. solution should be obtained from the chemist. It stains fats and medullated nerve fibres black. A $\frac{1}{4}$ per cent. solution can be used for hardening tissues.

Salt Solution.—Dissolve $7\frac{1}{2}$ parts of common salt in 1000 parts of water. This gives about $\frac{3}{4}$ per cent. solution of common salt. It contains a similar amount of common salt to the lymph found in the body, and is used for mounting fresh tissues in.

Sulphuric Acid.—Mix 1 part of the strong acid with 4 parts of water. Cane sugar is inverted when boiled with dilute sulphuric acid. It is also used as a test for cellulose along with iodine solution.

PREPARATION AND PRESERVATION OF SPECIMENS.—The following methods will be found useful for the preparation and preservation of specimens :—

COLD-AIR STORES.—Rabbits can be kept at the cold-air stores or in a refrigerator, and in this way a good number of dissections can be made on the same animal.

DECALCIFYING LONG BONES.—Place the long bone in a 10 per cent. solution of common salt, and add 2 parts of strong hydrochloric acid. Examine and add to the solution each day a few drops of the acid until the bone becomes flexible. Soak the flexible bone in water to remove the acid.

RABBIT SKELETON.—Collect the bones of the rabbit, and boil in water to soften any flesh which may adhere to them. Change the water several times until the bones are clean. Dip each bone in weak sulphuric acid, and place on chloride of lime for a few minutes. The acid liberates chlorine, which bleaches the bone. Well wash the bones under running water to remove the acid and chlorine, and dry.

SHEEP'S HEARTS.—Place the sheep's hearts in strong salt brine, which will remove the blood, and make them much better for examination. They can be kept in salt brine for several weeks.

SPINAL CORD AND BRAIN.—(*a*) The spinal cord of the sheep can be hardened in a $\frac{1}{4}$ per cent. solution of chromic acid for 48 hours. Then keep in methylated spirits.

(*b*) Remove the upper bones from the cranium of the sheep, and keep the head in a $\frac{1}{4}$ per cent. solution of chromic acid, or in a 4 per cent. solution of formalin, until the brain is required for examination.

MOUNTING SPECIMENS.—The glass slide should be cleaned; this can be done by dipping it in water and rubbing both sides with a clean duster. Place a single drop of the mounting fluid in the centre of the slide, and spread it out with a cover glass. The clean cover-glass should be held between the first finger and the thumb of the left hand and steadied with the long finger. Allow it to touch the drop of mounting fluid with the edge, and lower into position with a pencil held in the right hand. This spreads out the drop, and prevents the enclosure of air-bubbles.

Remove a little of the very thin connective tissue from beneath the skin of a dead rabbit, and spread out on a glass-slide. Cover with a drop of salt solution or glycerine, and place the cover-glass in position. Remove a similar piece and place in a drop of salt solution; tease out with two pins or needles. This can be done by holding one portion of the tissue with a needle, and teasing with the other. Look at the tissue from time to time with the low power to see if the parts are separated. Full descriptions are given in the following chapters for preparing and mounting specimens for examination with the microscope.

QUESTIONS FOR REVISION

1. Give a brief history of Human Physiology.
2. Why is human physiology of such importance from a national point of view?
3. Describe the structure of the animal cell.
4. Explain the following terms: cell, tissue, protoplasm, nucleus.

5. What is meant by division of labour?

6. How would you proceed to decalcify a long bone? Describe the characters of such a bone.

7. How would you proceed to prepare and examine a specimen of connective tissue?

8. Write a short account of the properties and functions of protoplasm.

CHAPTER II

THE HUMAN BODY

ORGANS.—The hand is made up of a palm and five fingers or digits. Each long digit consists of three bones, which are covered with muscle and skin, and it can be used for the special work of grasping objects. Any portion of the body which is specialised for performing a special kind of work is said to be an **organ.** The work which an organ performs is spoken of as its **function.** The tongue contains the organs of taste, the eye of sight, and the ear of hearing. The life of the individual depends upon all the organs performing their proper functions, and if one ceases to do its due share of work, sickness or death may be the result.

The human body can be compared to a modern community, for the complete life of the latter depends upon all its units performing their special work. The strike of some of the workers in a modern community upsets the whole of its organisation, and affords a comparison to the case where one of the organs of man refuses to perform its proper work, for the whole of the body suffers through the incapacity of that unit. It is only by all the organs of the body being kept in good condition, so that they can perform their proper functions, that really good health can be enjoyed.

THE HUMAN BODY.—The human body consists of head, trunk, and limbs. The head can be divided into a cranium, which contains the brain, and a face,

which contains the special organs of the senses. The cranium is generally covered with hair, and it is made up of bones which protect the brain from injury. The face also consists of bones, such as the lower and upper jaws, which contain the teeth, and those which protect the eyes and ears.

The head is separated from the trunk by a neck; this varies in length in different individuals; the windpipe, food-gullet, and important blood-vessels pass through the neck. The back of the neck is made up of the neck vertebræ, and the prominent object in the front is the **larynx** or voice-box.

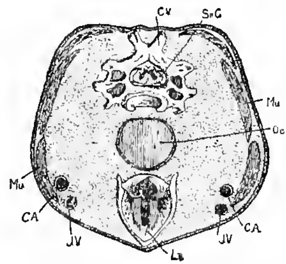

FIG. 2.—Transverse section of neck. *C.V.* cervical vertebra; *Sp.C.* spinal cord; *Mu.* muscles of neck; *Oe.* œsophagus; *C.A.* carotid artery; *J.V.* jugular vein; *L.R.* larynx.

The trunk can be divided into an upper cavity, the **thorax**, and a lower cavity, the **abdomen**. The thorax possesses bony walls in front, sides, and behind, while the floor is made up of the diaphragm, and the top by the roots of the neck. The abdomen possesses soft muscular walls in front and at the sides; the top is formed of the diaphragm, the back of the lumbar portion of backbone, and the floor of the basin of the pelvis.

Experiment 1.—(1) Stand in front of a looking-glass, and examine your head. Notice that it can be divided into (*a*) cranium, (*b*) face. The former protects the brain, and is generally covered with hair. The face contains the special organs of the senses, the eyes, ears, nose and tongue. The expression on the face is due to

the actions of muscles, which by their change of condition give animation to the features. The movements of these muscles depend upon impulses sent from the brain along the facial nerve; hence the face is an index to the mind.

(2) Notice the neck, which joins the head to the trunk. It varies in length in different individuals, and its flexibility gives movement to the head. Feel the windpipe, which runs down the front of the neck, and the prominent swelling of which is the **larynx.** The

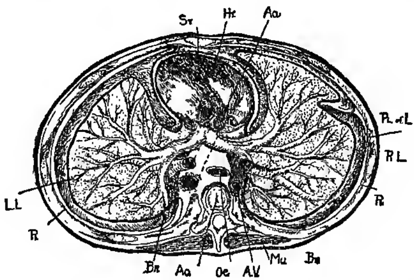

FIG. 3.—Transverse section of thorax. *Ao.* vertebra; *R.R.* ribs; *St.* sternum; *Mu.* muscles; *L.L.* left lung; *R.L.* right lung; *Pl. of L.* pleura of lung; *Ht.* heart; *Br.* bronchus; *A.V.* vena cava; *Aa.* aorta; *Oe.* œsophagus.

back is made up of vertebræ, and the head rests on the top vertebra, the **atlas.**

(3) Make out the boundaries of the trunk, which reaches from the neck to the hips. The upper cavity, the thorax or chest, possesses hard bony walls, which are shaped like a beehive. The lower cavity, the abdomen or belly, possesses soft walls which give way to pressure.

(4) Examine the upper limbs and how they are fixed to the trunk. Each arm can be moved round in a circle; this is due to the nature of the joint at the shoulder—a shallow ball-and-socket joint.

(5) In a similar way notice the firmness of the lower limbs, the legs, and that they carry the weight of the trunk and head.

THE ORGANS IN THE THORAX

The thorax contains the blood-circulating and purifying organs, and structures which pass through on their way to the abdomen.

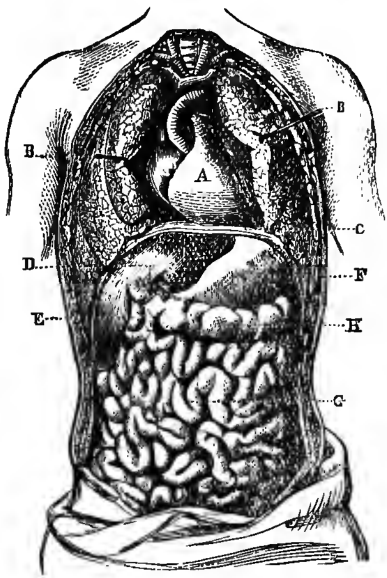

FIG. 4.—The human trunk with the front wall removed to show the position of the organs in the thorax and abdomen. *A*, heart; *BB*, lungs; *C*, diaphragm; *D*, liver; *E*, gall bladder; *F*, stomach; *G*, small intestine; *H*, transverse colon of large intestine.

THE HEART.—The heart is placed in the middle line of the thorax, just behind the sternum, and with the apex inclined to the left. It rests on the diaphragm,

and is supported by the great blood-vessels and strong cords which pass from the upper walls of the thorax. It is conical in shape, and works in a bag, the **pericardium**, which protects and limits its movements. The heart weighs about 10 ounces, is 5 inches long, $3\frac{1}{2}$ inches wide at its widest part, and about $2\frac{1}{2}$ inches in thickness. The broad end or base is uppermost, and the blood-vessels spring from this portion of the heart. The function of the heart is to force the blood to all parts of the body.

THE GREAT BLOOD-VESSELS.—From the base of the heart a series of blood-vessels arise, some of which carry blood to the heart, while others distribute it from that organ to all parts of the body. The pulmonary artery arises in the middle line and front of the heart, and the impure blood passes through it to the lungs to be purified, while the pulmonary veins return the pure blood to the left side of heart. The aorta arises to the right of and behind the pulmonary artery, and supplies pure blood to all parts of the body. The impure blood is returned from the lower portion of the body by an inferior vena cava, and from the upper portion by a superior vena cava.

THE WINDPIPE.—The air from the pharynx passes through the windpipe to the lungs. Its upper end is at the back of the mouth, and its lower end is in the thorax. It is kept open by rings of cartilage, and divides into a pair of tubes, the **bronchi**, which enter the lungs.

THE LUNGS.—The lungs are a pair of spongy organs which nearly fill the cavity of the thorax. They are pinkish in colour, very light and porous, and will float on water. The right lung fits into the thorax on

the right side, and possesses three lobes. The left lung in a similar manner fits into the left side of thorax, and is divided into two lobes. They are surrounded by a bag, the **pleura**, one layer of which lines the walls of the thorax, and the other adheres to the lung substance. The air enters the lungs down the windpipe, for the thorax is an air-tight cavity. In the blood-vessels of the lungs the blood is purified. The rate of breathing varies under different conditions, but averages from 15 to 17 per minute.

THE ŒSOPHAGUS OR FOOD GULLET.—The muscular tube which brings the food from the pharynx to the stomach is known as the œsophagus; it runs behind the heart, piercing the diaphragm, and opens into the stomach, which is in the abdomen.

THE THORACIC DUCT.—The thoracic duct is a tube about the thickness of the shaft of a quill-feather, which is placed just in front of the backbone. It is a storehouse for the fluids called chyle and lymph, which it receives from the alimentary canal and other parts of the body, and empties them into the blood-vessels at the junction of the great veins on the left side of the neck.

THE ORGANS IN THE ABDOMEN

The diaphragm separates the heart and the lungs from the stomach and liver; there passes through it the œsophagus, descending aorta, inferior vena cava, and thoracic duct (Fig. 4). The abdomen is lined with a membrane—the **peritoneum.**

THE STOMACH.—The stomach is placed just beneath the diaphragm, with its large or cardiac end

on the left side, and the small or pyloric end on the right side. It is shaped like a bagpipe, and the œsophagus enters on the upper surface near the cardiac end, where a sphincter or ring muscle guards its orifice. At the pyloric end there arises the duodenum or first portion of the small intestine. On the upper surface or lesser curvature the liver rests, and in the lower or greater curvature comes the pancreas. At the cardiac end comes the spleen, which is supported by a fold of

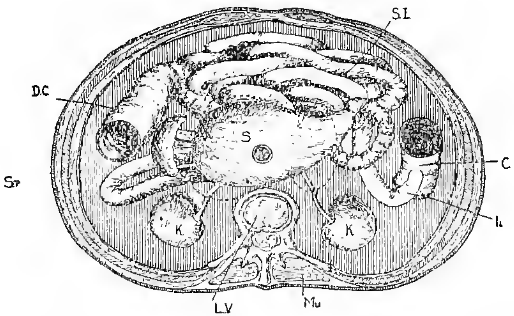

FIG. 5.—Transverse section of abdomen. *L.V.* lumbar vertebra; *Mu.* muscles of abdomen; *K.* kidney; *S.* stomach; *Il.* ileum; *C.* cæcum; *D.C.* descending colon; *S.L.* loop of small intestine; *Sp.* spleen.

the mesentery. The food is stored and partly digested in the stomach, and is prepared for intestinal digestion.

THE SMALL INTESTINE.—The small intestine arises at the pyloric end of the stomach on the right side of abdomen, and ends in the cæcum on the right side near the pelvic basin. It is a convoluted tube which is some 20 feet in length, and is folded and held in position by the mesenteric membrane, which is an infolding of the peritoneum. Both digestion and absorption take place in this portion of the alimentary canal.

THE LARGE INTESTINE.—The large intestine consists of a cæcum, at the end of which comes the vermiform appendix, a colon which ascends up the right side of abdomen, crosses beneath the stomach, and down the left side, where it ends in the rectum. It is from 6 to 8 feet in length, and is a sacculated tube, in which the soluble and diffusible materials are absorbed, and the waste materials leave it by the rectum.

SUMMARY OF POSITION OF ALIMENTARY CANAL.—The following gives the parts and position of the different portions of the alimentary canal.

Mouth		In the face.
Pharynx		
Upper portion of œsophagus		In the neck.
Middle portion of œsophagus		In the thorax.
Lower portion of œsophagus		In the abdomen.
Stomach		
Small intestine	Duodenum	
	Jejunum	
	Ileum	
Large intestine	Cæcum	
	Colon	
	Rectum	

THE LIVER.—The liver is a large reddish-brown organ, which weighs about 50 ounces, and fits into the concavity of the diaphragm on the right side, resting on the pyloric end of stomach. It is attached to the diaphragm by strong ligaments, and is roughly oblong in shape. On the under-surface the gall-bladder rests in a cleft, and the blood-vessels enter and leave the liver (Fig. 67). It forms bile and glycogen.

THE SPLEEN.—The spleen is situated on the left of the cardiac end of the stomach, and is suspended by a fold of the mesenteric membrane. It is a purple-red organ, of a spongy texture, and shaped like the palm of

the hand. Blood enters it by the splenic artery, and leaves by the splenic vein. It is a ductless gland, because its secretion is discharged directly into the blood, and it does not possess a duct. The red corpuscles of the blood die in the spleen, and colourless ones are formed in its substance. It changes its size from time to time, and seems to act as a storehouse for blood.

THE PANCREAS.—The pancreas is a milky-white gland which rests in the loop formed by the greater curvature of the stomach and duodenum, and it is from 8 to 9 inches in length. It touches the spleen, and its main duct joins the common bile-duct near the duodenum (Fig. 60). The pancreas secretes pancreatic juice, which aids the digestion of the food in the small intestine.

THE KIDNEYS.—The kidneys are a pair of reddish-brown organs which are fixed behind the peritoneum in the lumbar region of the abdomen and on either side of the backbone. Each kidney is shaped like a kidney-bean, and from its concave border, which faces towards the backbone, a duct arises—the **ureter**. It is 4 inches long, $2\frac{1}{2}$ inches wide, and 1 inch in thickness. Blood is carried from the aorta to the kidney by the renal artery, and the renal vein empties into the inferior vena cava. From the blood the kidneys separate urine, and this is discharged by the ureters into the bladder.

THE BLADDER.—The bladder is placed in the pelvic basin, whose bony walls protect it from injury. It is a pyriform body, in which urine is stored up until it can leave the body. Each ureter runs for a short distance in its walls before opening into the cavity, and

this prevents the backward flow of urine towards the kidney. The urethra or opening from the bladder is protected by a sphincter muscle, which is under the control of the will; on the relaxation of this the bladder can be emptied.

THE LIMBS

THE ARMS.—The arms, as we have seen (Experiment 1), are fixed so as to give the maximum amount of movement. Each arm is made up of the upper arm, or portion between the shoulder and elbow, the forearm between the elbow and wrist, and the hand. There are five digits or fingers, which vary in length, and the short one, the thumb, is very flexible.

THE LOWER LIMBS.—Each limb is made up of a thigh bone, which runs from the hip to the knee, the leg, which extends from the knee to the ankle, and a foot. The foot consists of a heel, sole, and five digits or toes.

SUMMARY OF STRUCTURE

1. The head { Cranium, which contains the brain. / Face, which contains the organs of the special senses.
2. The neck, which supports the head, and connects it to the trunk.
3. The trunk { The thorax, which contains heart, lungs, great blood-vessels, portion of œsophagus and windpipe, thoracic duct. / The abdomen, which contains the lower portion of the œsophagus, stomach, small intestine and large intestine, liver, pancreas, spleen, kidneys, bladder.
4. The upper limb, which consists of arm, forearm, and hand.
5. The lower limb, which consists of thigh, leg, and foot.

QUESTIONS FOR REVISION

1. What is an organ? Give examples.
2. Enumerate the parts present in the head. How is the head connected to the trunk?
3. Give the names, positions, and shapes of the organs contained in the thorax.
4. Define pericardium and pleura, and explain what important work they perform.
5. Describe briefly the general structure of *either* (*a*) the heart, or (*b*) the lungs.
6. What is the thoracic duct? Of what service is the thoracic duct?
7. State (*a*) the position of the abdomen, (*b*) the structure of its walls, (*c*) the organs which it contains.
8. Describe in outline the parts present in the alimentary canal, and give their position with regard to other organs.
9. Give the position, shape, and colour of the liver.
10. The spleen is said to be a ductless gland; explain this.
11. Define the position of the pancreas, spleen, liver, bladder, and kidneys.
12. What parts are present in (*a*) an upper limb, (*b*) a lower limb?

CHAPTER III

THE HUMAN SKELETON

The human skeleton forms the supporting framework of the body, and it is built up of bone and cartilage. It can be divided into :—

1. The backbone, or vertebral column, to which the ribs and sternum are attached.
2. The skull, which is supported by the vertebral column.
3. The shoulder or pectoral girdle, and a pair of upper limbs.
4. The hip or pelvic girdle, and a pair of lower limbs.

We will now consider the structure and arrangement of the different parts of the skeleton.

THE STRUCTURE OF BONE AND CARTILAGE

Experiment 2.—(1) Obtain from a butcher a sheep's foot, and remove the upper long bone. Examine, and note (i) that the ends of the bone are covered with a bluish white substance which is known as **cartilage** or gristle. (ii) Raise with a knife the membrane which covers the bone and which joins the cartilage—the **periosteum**. (iii) Remove a piece of the periosteum from the bone, and note its character. (iv) Lay bare the ends of the bone, and find the spongy or **cancellous** bone, which is covered with a thin layer of firm or

compact bone. (v) Examine the shaft or central portion of the bone which is composed of **compact** bone.

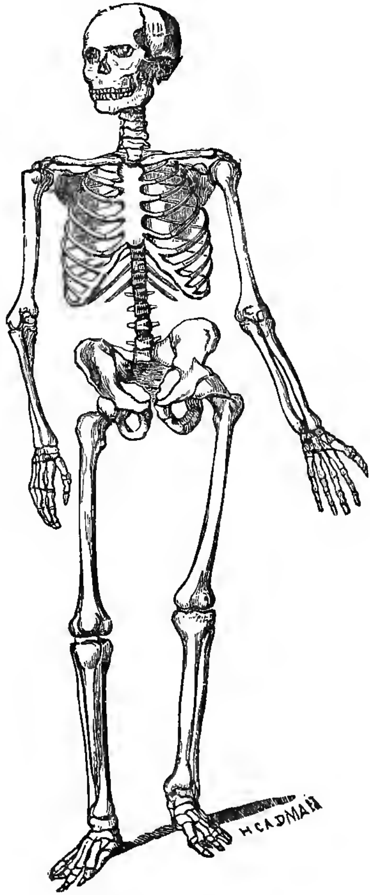

FIG. 6.—The Human Skeleton.

(2) Cut with a saw the bone used above lengthwise or from end to end, and note the medullary or marrow

canal. This contains (i) yellow marrow in the compact bone of the shaft, and (ii) red marrow at the ends in the cancellous bone.

(3) Now burn a piece of the bone over the Bunsen flame until all the animal matter has been burned off. Note the smell, and that a perfect model of the bone is left in mineral matter; this is very brittle and easily broken.

(4) Place a fresh long bone which has been obtained from a butcher in a 10 per cent. solution of common salt, add 2 parts of hydrochloric acid (p. 11). At the end of a week a perfect model of the bone will be obtained in animal matter, the acid having removed all the mineral matters. The model is very soft, and can be twisted into a knot.

(5) If possible, examine a transverse section of a long bone with a microscope (Fig. 8), and note (i) the Haversian canals; (ii) the bone lamellæ; and (iii) the bone cells or corpuscles. In the living bone the Haversian canals contained blood-vessels for its nourishment.

Experiment 3.—(1) Obtain from the butcher a costal cartilage or cartilage which unites the rib to the sternum, and carefully examine it. Note (i) the membrane which surrounds the rib cartilage—the **perichondrium.** (ii) Try and stretch the piece of cartilage; it is slightly elastic and very strong.

(2) Burn a piece of cartilage over the Bunsen flame, and note the very small quantity of mineral matter or ash which remains; the rest has disappeared, or is combustible.

(3) If possible, examine a prepared section of cartilage, or cut a very thin slice from the end of a long bone. Mount on a glass slide in a drop of ordinary salt solution. Look with the microscope for the cartilage

cells, which are imbedded in a matrix of cement substance (Fig. 7). Note the cells are arranged in groups of two, three, or four, and single cells may be seen. This is known as hyaline cartilage.

THE COMPOSITION OF BONE.—A fresh bone is composed of animal and mineral matters, and they are so closely connected that only by the use of acids or heat can they be separated (p. 27).

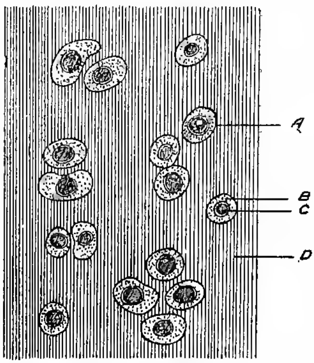

FIG. 7.—Section of hyaline cartilage. *A*, cartilage cell; *B*, cell protoplasm; *C*, nucleus; *D*, clear matrix.

If such a bone is placed over the Bunsen flame or on a bright fire, the animal matter is burnt off, and a model of the bone is obtained in mineral matter. The burnt bone is brittle and easily broken. On the other hand, if a fresh long bone is placed in salt solution and hydrochloric acid for some time, a model of the bone will be obtained in animal matter. The demineralised bone is soft and flexible, and can be twisted into a knot. The composition of bone is :—

Animal matter	33 per cent.
Phosphate of lime	54 „
Carbonate of lime, Fluoride of lime, Phosphate of magnesium } . . .	11 „
Other substances	2 „

THE STRUCTURE OF BONE.—There are two kinds of bone in the human skeleton, viz. compact or dense bone, and spongy or cancellous bone (p. 25). The

compact forms the shafts of the long bones, and generally a thin layer of it covers the cancellous bone. This is especially the case in the carpal bones, where a very thin layer of compact bone covers the mass of cancellous tissues beneath. The long bones contain cavities which are known as medullary canals, and these contain marrow. The canals in dense bone contain yellow marrow, and those in cancellous bone red marrow (p. 27). The articular ends of bones are covered

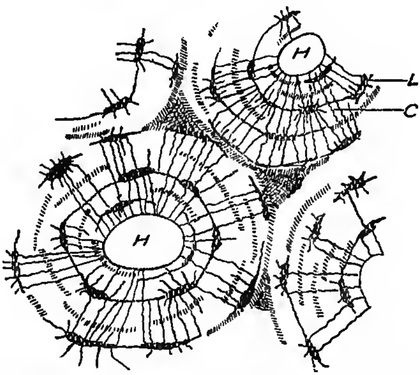

FIG. 8.—Transverse section of bone (humerus). *H.* Haversian canals; *L.* lacunæ; *C.* canaliculi. The dark bodies are bone corpuscles or cells.

with hyaline cartilage, and this gives smooth surfaces which are slightly elastic. All the bone, except where covered with cartilage, is surrounded by the membrane known as the periosteum. The blood-vessels for the nourishment of the bone enter the periosteum, where they break up and pass into its substance.

The bone consists of a framework of animal matter in which mineral matters are deposited in the form of bone lamellæ (Fig. 8). These are arranged around a number of openings, which contain bone corpuscles or cells which possess numerous processes. The larger

openings seen in a microscopic section of bone are the Haversian canals, and in living bone they contain blood-vessels.

The cancellous bone is light but very strong, and because it forms the ends of the long bones their weight is reduced. Compact bone is very strong, but much heavier in proportion to size than the cancellous bone, and it forms the thinner shafts of the long bones.

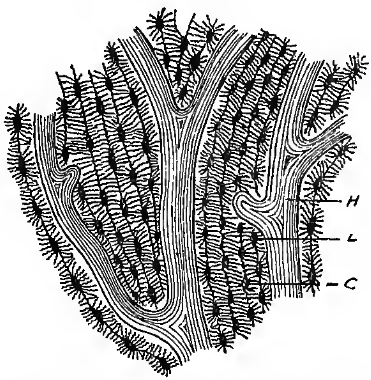

FIG. 9.—Longitudinal section of bone (humerus). *H.* Haversian canal; *L.* lacuna; *C.* canaliculi with bone corpuscle.

THE STRUCTURE OF CARTILAGE.—Gristle, or cartilage, is made up of animal matter, and only a very small quantity of mineral matter enters into its composition. A membrane covers the cartilage, and this is known as the perichondrium. Blood-vessels enter the perichondrium, but there are no blood-vessels in cartilage, and it is nourished by a colourless fluid, the **lymph**, which receives nutritive substances from the blood in the surrounding membrane. Cartilage is strong, slightly elastic, and can be compressed. It

is used where strength combined with elasticity are required.

Cartilage, as seen in thin sections under the microscope, consists of cells and a matrix. The matrix in hyaline cartilage looks like ground glass, but that in fibro-cartilage contains fibres. The following illustrates the kinds of cartilage, and where found.

1. **Hyaline Cartilage,** found in articular ends of bones, costal cartilage, larynx, a portion of sternum, windpipe, and bronchi.

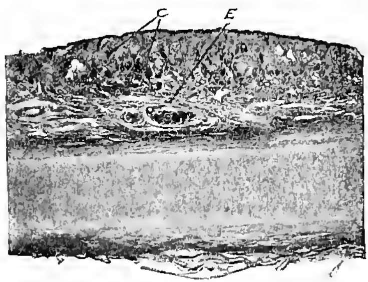

FIG. 10.—Section through pinna of cow's ear, showing yellow fibro-cartilage. *C.* cartilage cells embedded in a matrix; *E.* elastic fibres. (Photomicrograph by Flatters, Milborne & McKechnie.)

2. **White Fibro-Cartilage.**—The matrix contains white fibres; it is found in the pads of cartilage between the vertebræ.

3. **Yellow Fibro-Cartilage.**—The matrix contains yellow fibres; it is found in the epiglottis and external ear.

THE FORMATION OF BONE.—The bones in the human skeleton have been formed by the ossification or deposition of mineral matters in pre-existing

cartilage and connective tissue. From this peculiarity it is usual to divide bones into two classes, as—

1. **Cartilage Bones**, when formed from cartilage, as most of the bones of the trunk, limbs, and skull.

2. **Membrane Bones**, when formed from connective tissue; the clavicles, jaws, and roofing bones of skull can be mentioned as examples.

FIG. 11.—Side view of the vertebral column, showing the vertebræ placed one above the other, and forming a series of curves. *a*, atlas; *t*, lowest vertebra of cervical region; *c*, lowest thoracic vertebra; *d to e*, sacrum; *f*, coccyx.

All the bones in a very young child are mapped out in either cartilage or connective tissue, and the growth of the humerus may be taken as an example of the formation and growth of a long bone. It consists of a shaft, and two ends which are known as epiphyses. The cartilage in the shaft is absorbed in such a way that numerous blood-vessels can enter from the perichondrium, and this divides it into cavities, which are separated by layers of cartilage. Mineral matters are now deposited in the layers between the cavities. Bone cells enter the cartilage from the perichondrium, and begin to form true bone from mineral matters which are supplied from the blood. This process is continued until the cavities form the Haversian canals, and from the layers between them arise the bone-lamellæ.

In the humerus, as in all long bones, growth proceeds between the epiphyses and the shaft, and not until the adult condition is reached does the formation of bone from cartilage cease; for fresh cartilage is formed as quickly as it is converted into bone, and layers remain throughout life at the ends—as the **articular cartilage.**

THE PROPER FOOD FOR BONE BUILDING.—From the short description given of the formation and growth of bone, it will have been noted that in an infant the skeleton is in process of formation, and that most of it pre-exists in cartilage and connective tissue. If the skeleton is to be formed in a natural manner, the food supplied to the infant must contain suitable mineral substances. For the first ten months of life milk should be the only food, as it contains the phosphate and carbonate of lime in the right proportion and in a form suitable for assimilation. The most perfect method of feeding an infant is to feed it with mother's milk, but, failing this, cow's milk can be substituted.[1] During the whole period of growth a liberal supply of milk should be used with other suitable foods, so that the bones may become strong and well formed.

THE STRUCTURE OF THE VERTEBRAL COLUMN

The vertebral column is made up of thirty-three bones, which are known as vertebræ, and these can be classified into—

The Region in which Found.	*No. of Vertebræ.*
1. The cervical vertebræ in the neck region . .	7
2. The thoracic vertebræ in the thoracic region .	12
3. The lumbar vertebræ in the lumbar region . .	5
4. The sacral vertebræ in the sacral region . .	5
5. The coccygeal vertebræ in the coccyx region .	4
	33

[1] *The Student's Hygiene*, pp. 49–52.

Experiment 4.—(1) Obtain a thoracic vertebra, and determine—(i) The body or centrum, which is shaped like a bung and carries a neural arch (Fig. 12). (ii) Examine the neural arch, and find the spinous process which is directed backwards and downwards. Look for the pair of transverse processes which point outwards. Find the smooth places or facets which are covered with cartilage on these processes and on the centrum. These are for the articulating of a pair of ribs. (iii) Find the deep notches on the neural arch; these are for the passage of a pair of spinal nerves, and they receive the name of **intervertebral foramen.** (iv) Observe the two pair of articulating processes by which the vertebra is locked to the vertebræ above and below. (v) Note the cavity enclosed by the neural arch and centrum, the spinal canal or portion of neural tube.

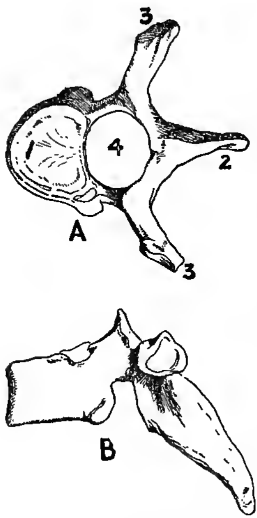

FIG. 12.—The sixth thoracic vertebra. *A*, plan looking down; *B*, side view as seen from the left. 1, body of vertebra; 2, spinous process; 3, transverse process; 4, portion of neural tube. Note that all the vertebra except the body forms the neural arch.

(2) Obtain a complete vertebral column, and make out the parts given in the column on p. 33. Note the general characters of the different vertebræ. (i) The seven cervical vertebræ have short spinous and transverse processes, and the centræ are not well developed. (ii) The twelve thoracic ones have the characters discovered in (1) above. (iii) The five lumbar vertebræ are very strong and large; their spinous processes point backwards, and

the transverse and articulating processes are well developed. (iv) The five sacral vertebræ are fused together to form the wedge-shaped sacrum, and a number of processes at the sides are termed sacral ribs by which the sacrum articulates with the os innominata (Fig. 11). (v) Find the four coccygeal vertebræ which form the coccyx or caudal region. They are the smallest of all the vertebræ, and cannot be of much service.

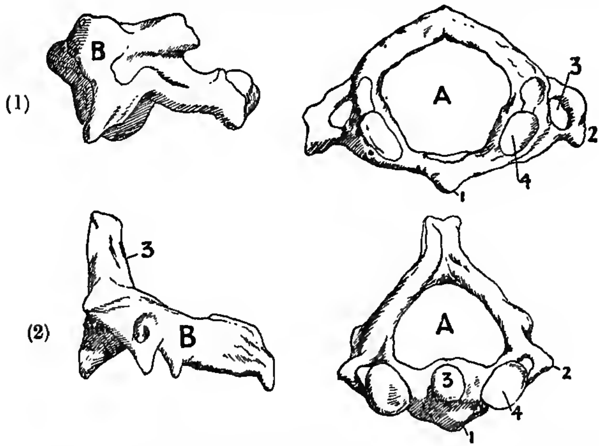

FIG. 13.—(1) *A*, plan of atlas; *B*, atlas as seen from the side. 1, neural spine; 2, transverse process; 3, vertebrarterial canal; 4, surface for the articulation of condyle of skull.
(2) *A*, plan of axis; *B*, axis as seen in side view from the left. 1, neural spine; 2, transverse process; 3, odontoid peg; 4, articulating surface on which the atlas rests.

Sketch and name the parts present in the vertebral column. (vi) Note the pads of cartilage which fit in between the vertebræ, the **intervertebral discs.**

Experiment 5.—(1) Remove the top cervical vertebra, the **atlas,** and note that it is a ring-like bone, which does not possess a centrum. The spinous and transverse processes are represented by very short outgrowths, and the upper surface of the atlas contains

depressions into which the pair of condyles on the skull fit. The lower surface is hollowed out so that it fits over the saddle-shaped axis. Note the large opening, which in life contains the upper portion of spinal cord. At the base of each blunt transverse process there will be seen an opening, the **vertebrarterial canal**, which during life carries a blood-vessel.

(2) Now examine the **axis**, as the second cervical vertebra is called. It possesses a well-defined process, the **odontoid peg**, which fits into the back of the atlas. This is the missing centrum of the atlas which has become connected to the body of the axis. Note the shape of the axis, and place the atlas in position; the two form a saddle joint like the neck vertebræ of a bird. The atlas can move through an angle of about 180° round the odontoid peg, and this forms a pivot joint.

(3) All the other cervical vertebræ have the characters given in the previous practical work, except that the processes are short, and at the base of each transverse process there is a vertebrarterial canal.

THE VERTEBRAL COLUMN OR BACKBONE.—The thirty-three vertebræ articulate to form the backbone or vertebral column, which is bent into a number of curves. The vertebræ are joined together by ligaments; these are strong cords which are slightly elastic, and this property enables a certain amount of movement between the bones. The ligaments pass from vertebra to vertebra in such a way that a very flexible structure is produced. In addition to ligaments, the inter-vertebral discs of cartilage help to unite the vertebræ, and due to their elastic property they counteract shock. Even the curved shape of the vertebral column has to do with the prevention of shock to the spinal cord and the brain. (See p. 32.)

SUMMARY OF STRUCTURE OF THE VERTEBRAL COLUMN

Name of Vertebræ.	No.	Characters of.	Attachment.	Uses.
Cervical Vertebræ.	7	*Atlas*—The body is a mere ring, and the spinous process much reduced (Fig. 13). *Axis*—The body carries the odontoid process. *The other vertebræ* of the ordinary type, but with transverse processes perforated to carry blood-vessels and much reduced spinous processes.	The atlas and axis form a pair of joints, and the condyles of the skull articulate with the atlas. The odontoid process of the axis fits into the ring of the atlas.	To carry the head, and give movement to it by means of a joint between skull and atlas, and a pivot joint between the atlas and axis.
Thoracic Vertebræ.	12	Of the typical form described in Experiment 4.	The ribs articulate with them.	To carry the ribs, and support the cervical region and skull. They also form the back of the thorax.
Lumbar Vertebræ.	5	Of the usual type, but much larger and stronger.	The upper one articulates with the portion of the vertebral column above.	They support the whole of the bones above, and help to carry the organs and muscles of the abdomen.
Sacral Vertebræ.	5	They are united to form a wedge-shaped bone, the sacrum (Fig. 11).	The sacrum is wedged in between the hip bones.	The sacrum is the keystone of the pelvic girdle.
Coccygeal Vertebræ.	4	They form the coccyx.	They are connected to the sacrum.	Rudimentary.

THE RIBS AND STERNUM.—The twelve pairs of ribs help to form the walls of the thorax. The upper ribs are very short, and they increase in size from the first to the fifth or sixth, below which there is a decrease in size. The fifth rib is curved from back to front, and forms a semicircle. It articulates to the facets on the transverse process and centrum of vertebra, and its costal cartilage unites it to the sternum. In transverse

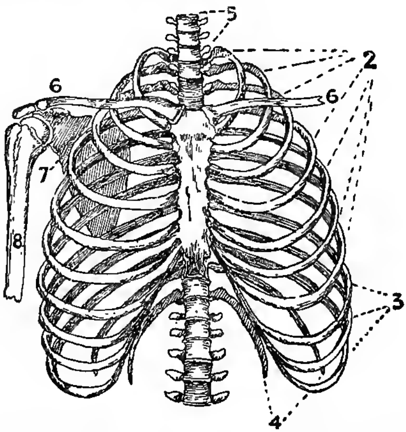

FIG. 14.—Diagram of walls of thorax and pectoral girdle. 1, sternum ; 2, true ribs ; 3, false ribs ; 4, floating ribs ; 5, cervical vertebræ ; 6, clavicle ; 7, scapula ; 8, humerus.

section the rib is seen to be flattened at the sides, and to form roughly an ellipse. The seven pairs of upper ribs are united to the sternum by costal cartilages, and are known as *true* ribs. The costal cartilages of the eighth pair are united to the costal cartilages of the seventh pair, the ninth to the eighth, and the tenth to the ninth. These form the so-called false ribs. The lower two pairs of ribs do not possess costal cartilages, but are embedded in the muscles of the thorax. They are known as floating ribs.

The sternum or breast bone is shaped like a dagger, with the broad end upwards and the pointed end downwards. It is made up of seven bony segments, which are united by cartilages.

Experiment 6.—(1) Obtain and examine the human sternum. Note (i) it is a dagger-shaped bone, broad above, and tapering to a blunt point below. (ii) Find the segments of which it is made up; they consist of bone and cartilage.

(2) Note the shape of the fifth or sixth rib; it is a curved bone, the costal cartilage of which unites it to the sternum. Find the two processes by which it articulates with the transverse process and centrum of vertebræ.

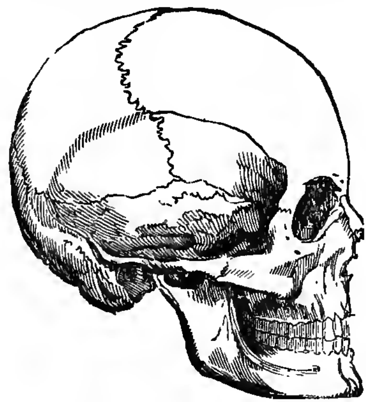

FIG. 15.—The human skull. Note the sutures, which mark the joints between the bones of the cranium.

(3) Count the ribs; there are seven, which are united to the sternum by costal cartilages, and three indirectly by cartilages; the two others are embedded in the living body, in muscles.

THE GENERAL STRUCTURE OF THE SKULL

The human skull consists of a hard, strong brain-case or **cranium,** which contains the brain, and a face, which is made up of a number of bones which protect the organs of the senses.

Experiment 7.—Obtain a human skull, and place it on the table so as to show the parts seen in Fig. 15.

(1) Note the flat bones which unite or interlock by a series of sutures. Each flat bone is made up of thin layers of compact bone, between which there is sandwiched a layer of cancellous bone. This gives the maximum amount of strength for the thickness, and helps to reduce shock to the brain.

(2) Carefully examine the base of the skull, and find (i) the pair of condyles which articulate with the atlas; (ii) the large round hole through which the spinal cord passes, the **foramen magnum.**

(3) Now examine the face, and note the numerous bones which form its bony framework. Find (i) the large **orbits,** or eye-sockets; (ii) the tympanic bones of the ears, which contain a number of ossicles; (iii) the **nasal bones**; (iv) the well-developed upper **jaw,** which contains sockets for the upper sixteen teeth. Note a pair of depressions or pits which will be seen in front of the ears. These are for the articulation of the lower jaw. (v) The lower jaw consists of two bones, which are fused together, and it articulates to the sockets in the upper jaw by a pair of rounded condyles. This forms what is called a hinge-joint. The lower jaw also contains sockets for sixteen teeth.

The cranium, as we have seen, is made up of a number of flat bones, which interlock so as to form a strong structure, in which the brain is protected from shock and injury. The bones of the cranium grow at their edges by the addition of new bony tissue, and this enables the size of the skull to keep pace with the growth of the brain. In addition to the external bones there are a number of internal bones,

which help to form the base of the cranium and to increase its strength.

The bony framework of the face is made up of numerous bones. These are so arranged that they contain orbits or sockets for the eyes, the bones of the ears, the nasal sockets, and the jaws. The upper jaw is made up of two fused bones, and these contain sixteen teeth-sockets. In the lower jaw there are two fused bones, and it articulates by its condyles with the cavities of the squamosal bones. It contains sockets for sixteen teeth.

SUMMARY OF STRUCTURE OF SKULL

Division of Skull.	Name of.	Names of Bones in Segment.	Attachments, &c.
Cranium.	Occipital segment which is formed of four bones.	Basi-occipital; two ex-occipitals; supra-occipital.	It surrounds the foramen magnum, and is connected to the atlas by a pair of occipital condyles.
	Parietal segment which is formed of five bones.	Basi-sphenoid; two alisphenoids at the sides; two large parietals in front.	It is connected to the occipital segment behind and the frontal segment in front.
	Frontal segment which is formed of three bones.	Presphenoid; two orbito-sphenoids.	It joins the parietal segment behind.
The principal bones of the face and sense capsules.	The auditory capsule consists of three bones on either side.	Periotic bone.	The periotic bone, which contains the inner ear.
		Tympanic bone.	The tympanic bone contains the three ossicles, the malleus, incus, and stapes.

SUMMARY OF STRUCTURE OF SKULL—*continued*

Division of Skull.	Name of.	Names of Bones in Segment.	Attachments, &c.
The principal bones of the face and sense capsules.	The auditory capsule consists of three bones on either side.	Squamosal bone.	The squamosal bone articulates with the parietal segment above, and the supra-occipitals behind.
	The olfactory capsules consist of a number of bones on either side.	Nasal bones.	The pair of nasal bones form the upper portion of the olfactory cavity of nose.
		Turbinal bones.	The turbinal bones form the sides of the olfactory cavity, the ethmoturbinals the back, and the hard palate or maxilloturbinals the floor.
	Optic capsule.	Lachrymal.	Only a single bone belongs to the optic capsule on either side—the lachrymal.
	The upper jaw.	Formed of a number of fused bones.	It contains sockets for sixteen teeth, and is closely connected with the olfactory capsules and cranium.
	The lower jaw.	Formed of two fused bones.	The upper ends form condyles which articulate with the glenoid cavities of the squamosal bones.

QUESTIONS FOR REVISION

1. Of what parts does a long bone consist? What is the composition of bone? How can the animal and mineral matters present in a bone be separated?
2. Describe the gross and minute structure of bone.
3. How is bone nourished and formed?
4. Explain how bone differs from cartilage.
5. What food especially aids the building of bone, and why in badly-nourished children are the bones not well formed?
6. Classify the vertebræ in the vertebral column.
7. Describe the structure of a typical vertebra.
8. Explain how the vertebræ are united to form the vertebral column.
9. Give an account of the structure and articulation of the atlas and axis.
10. What is the structure and articulation of the fifth rib?
11. Define the position of the sternum. To what structures is the sternum articulated?
12. Describe the structure of the skull.
13. How is the lower jaw articulated to the face, and what kind of a joint does it form?
14. Explain as far as you can the position of the bones which form the cranium, and how they unite together.
15. Show by a sketch the principal bones of the face.

CHAPTER IV

THE HUMAN SKELETON—*Continued*

THE PECTORAL GIRDLE AND UPPER LIMBS.—The pectoral girdle consists of four bones, a pair on either side, which are known as the shoulder blade or scapula, and a collar bone or clavicle. Each upper limb contains thirty bones. We will now consider the arrangement and structure of the above bones.

Experiment 8.—(1) Obtain a human scapula, and note (i) the shape. It is roughly triangular, and flattened from side to side. (ii) At the corner of the scapula there is a shallow cavity which is known as the **glenoid cavity,** and to which the arm articulates. (iii) The short curved process near the glenoid cavity, and which receives the name of **coracoid process.** (iv) The much larger acromion process (Fig. 18).

(2) In a similar manner examine the shape and structure of the clavicle. It is a small rounded bone which runs from the scapula to the sternum (Fig. 16).

(3) Now examine the **humerus.** Note that it is a long bone which runs from the shoulder to the elbow. The upper end is enlarged and rounded, and is covered with cartilage where it fits into the glenoid cavity. The lower end is shaped like a pulley, and this articulates with the bones of the forearm. *Sketch and describe.*

(4) Examine your arm and find the **radius** and **ulna.** These run from the elbow to the wrist. The radius

is in a direct line with the thumb, and the ulna with the little finger. Now make out on the skeleton (i) the lower end of the ulna, which is small and nearly round, and at the upper end a large process, the **olecranon process**, which fits into a depression at the back of the humerus. This limits the movement of the forearm. Find the depression in the upper end of the ulna, with which the humerus articulates. (ii) Find the lower broad end of the radius which supports

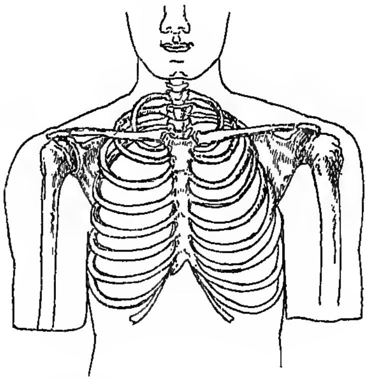

FIG. 16.—Front view of upper portion of trunk, showing position of sternum, ribs, clavicles, scapulæ, left humerus and right humerus.

the hand, and the small rounded end. *Sketch and describe.*

(5) Examine the wrist, which is made up of two rows of small irregular-shaped bones—the eight **carpal bones**. The upper row nearest to the forearm articulates with the radius, and the lower row supports the five metacarpal bones.

(6) Note the five **metacarpal bones** which form the palm of your hand, and compare with those on the skeleton. They are long bones of cylindrical shape.

(7) Count the fourteen **phalanges**, which form the five fingers or digits. They are similar in shape to

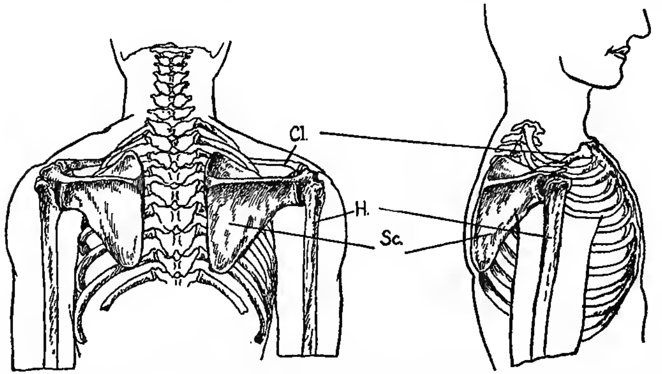

FIG. 17.—A posterior and side view of pectoral girdle. *Sc.* scapula; *Cl.* clavicle; *H.* humerus.

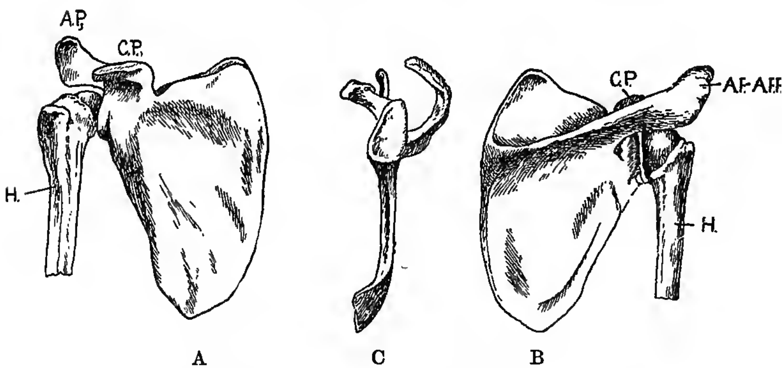

FIG. 18.—Different views of scapula and humerus. *A*, front view; *B*, back view; *C*, view of glenoid cavity. *H.* humerus; *C.P.* coracoid process; *A.P.* acromion process.

the metacarpal bones, but are of unequal length. Each digit is made up of three bones, except the thumb, which possesses only two.

THE STRUCTURE OF THE PECTORAL GIRDLE. —The girdle of bones across the shoulder are known as the shoulder or pectoral girdle. On either side there are two bones, the scapula and clavicle. The former is a flattened triangular-shaped bone, which is firmly connected to the skeleton of the thorax, and this gives a firm support to the upper limb. At one corner of the scapula there is a shallow glenoid cavity in which the head of the humerus fits, and over which a well-developed coracoid process stands. If the arm is elevated, it comes in contact with this process, and that side of the thorax is raised and the other side depressed.

FIG. 19.—Two views of clavicle. *A*, front view ; *B*, plan.

The comparatively long clavicle is connected to the scapula and sternum, and forms a kind of wedge between them.

THE STRUCTURE OF THE ARM AND HAND.— The following gives the position and arrangement of the bones of the arm and hand.

1. **The upper arm** is made up of a single long bone, the humerus, and it comes between the scapula and forearm. The upper end is large and rounded, and is covered with cartilage. It forms a joint with the glenoid cavity of scapula. The lower end is pulley-like, and it forms a joint with the bones of the forearm.

2. The **forearm** is made up of two long bones, the radius and ulna, and they come between the lower end of the humerus and wrist. The radius is in a direct

line with the thumb, and its broad end supports the hand, while its upper end is small and rounded. The ulna is in a direct line with the little finger, and its upper end bears a large process and a depression. The process is known as the **olecranon process,** and it limits the movement of the forearm, while the lower end of the humerus fits into the depression. The lower end of the ulna is small and rounded, and because the upper end of radius and lower end of ulna can freely move, the rotation of the hand is obtained.

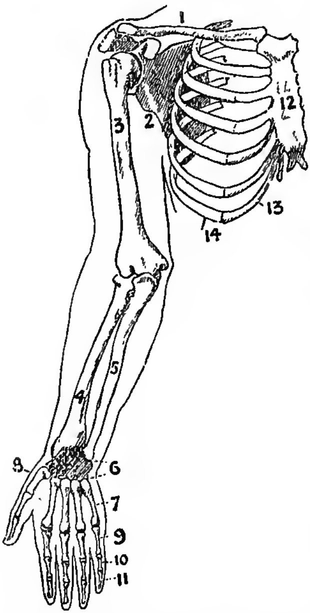

FIG. 20.—Pectoral girdle, bones of arm and hand, with ribs and sternum. 1, clavicle; 2, scapula; 3, humerus; 4, radius; 5, ulna; 6, carpal bones; 7, metacarpal of little finger; 8, metacarpal of thumb; 9, 10, 11, phalanges of little finger; 12, sternum; 13, costal cartilage of rib; 14, rib.

3. The **wrist** is made up of eight carpal bones, and these are arranged in two rows. The carpal bones are irregular in shape, and well adapted for counter-acting shock. Each bone can move a little, and this makes the wrist flexible. The upper row of bones articulate with the radius and ulna, and the lower row with the metacarpal bones of palm.

4. The **palm** of the hand is formed of five meta-carpal bones. Each bone is long and rounded, and they support the digits. The metacarpal, which carries the thumb, rests on a saddle-shaped carpal bone, and

its end is hollowed out so that it fits like a rider on the bone.

5. The **digits** differ in length, and four of them consist of three phalanges each, but the thumb is made up of two phalanges.

THE STRUCTURE OF THE PELVIC GIRDLE AND LOWER LIMBS.—The girdle of bones at the hips form the pelvic girdle; it supports the upper portion of the body, and in turn rests on the lower limbs. The bones which form this girdle are firmly attached together to form a basin-shaped structure, the **pelvic basin**. We will now consider the structure and position of the pelvic girdle and lower limbs.

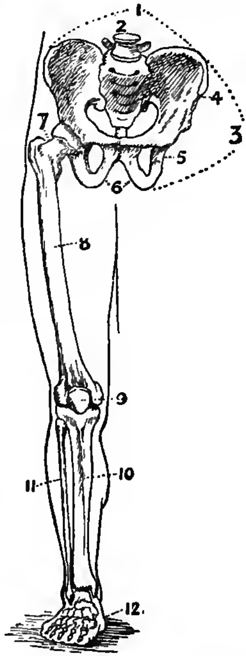

FIG. 21.—Pelvic girdle, leg, and foot. 1, pelvic girdle; 2, sacrum; 3, os innominatum; 4, ilium; 5, ischium; 6, pubis; 7, head of femur; 8, femur; 9, patella; 10, tibia; 11, fibula; 12, foot.

Experiment 9.—(1) Obtain a hip bone from a human skeleton, and study its structure in detail. Note (i) the irregular shape of the bone, and that on the outer side of the bone there is a deep cup, the **acetabulum cavity.** (ii) Turn the acetabulum cavity outwards so as to bring the large opening forwards. The portion above is known as the **ilium**, while the outer portion below it receives the name of **ischium**, and the inner forms the **pubis**. Sketch and describe, and note

that the bones enumerated above are fused together to form the hip bone or **os innominatum.** (iii) Now examine the full pelvic basin, noting (*a*) its shape, which is arched to give additional strength for the support of the trunk, and the basin-shaped cavity which the bones enclose. (*b*) The two hip bones are firmly connected behind to the wedge-shaped sacrum by means of sacral ribs, as the irregular processes of the bones are called, and in the living body by ligaments. In front the bones are also firmly united by ligaments.

(2) Sketch and describe the structure of the femur, as the thigh bone is called. Note (i) It is a long bone, at the upper end of which there is a swelling (see Fig. 23, *Ar.S.*), which is covered with cartilage, and fits into the acetabulum cavity in the os innominatum. (ii) The lower end is converted into a pair of large condyles which rest on the top of the tibia, and between which there will be seen an intercondylar notch, in which the patella moves.

(3) Examine the patella. Note that it is shaped like the shell of the limpet, and that it fits between the lower end of femur and top of tibia.

(4) Now carefully examine the appearance of the tibia and fibula. (i) Make a sketch of the tibia, and note that it extends from the knee to the ankle. On the upper surface there are a pair of oval depressions in which the condyles on the femur rest. Just below the upper end there will be seen a well-developed projection, the **enemial crest.**

The edge of the bone points forwards, and as seen in section the bone is triangular. At the lower end there is a cup-like surface for articulating with the first tarsal bone. (ii) In a similar manner examine the fibula. It is a long bone like the tibia. Its upper end is united with the tibia above, and it extends past

the lower end of that bone to the ankle, the outer portion of which it helps to protect.

(5) Find the seven tarsal bones which form the ankle. The first, upon which the tibia rests, has a rounded surface, and is known as the **astragalus.** At the back and below the astragalus there is a bone which forms the heel, the **os calcis** or **calcaneum,** and in front of these there will be found the **scaphoid** bone. The three tarsal bones enumerated above form the first row, and a second row in front consists of four bones. The outer one, which comes between the instep and calcaneum, is the **cuboid** bone, while in front of the scaphoid bone there are three cuneiform bones. Sketch and describe.

(6) Now find the five metacarpal bones of the sole of the foot; they are long bones, but vary in length.

(7) Examine the five digits of the foot, and note that they vary in length, but each consists of three phalanges, except the big toe, which is made up of two phalanges.

THE STRUCTURES OF THE PELVIC GIRDLE.—The series of bones which support the trunk form the pelvic girdle; it is made up of three bones, a pair of hip bones at the sides, and a keystone at the back, the sacrum. Each hip bone or os innominatum possesses a deep cavity for the articulation of a femur, and in a young child, where the bones have not completely fused, three distinct bones can be seen—the ilium, ischium, and pubis. The point of junction of these bones comes in the acetabulum cavity (Fig. 22). The union of the sacrum and the two hip bones forms the pelvic basin, which protects a number of important organs.

THE THIGH.—In the thigh there is one bone, the **femur.** The femur is a long bone, which extends from the hip to the knee, and at the upper end there is a strong process, the **trochanter.** The head is at the end of a distinct neck, which is set at nearly right angles to

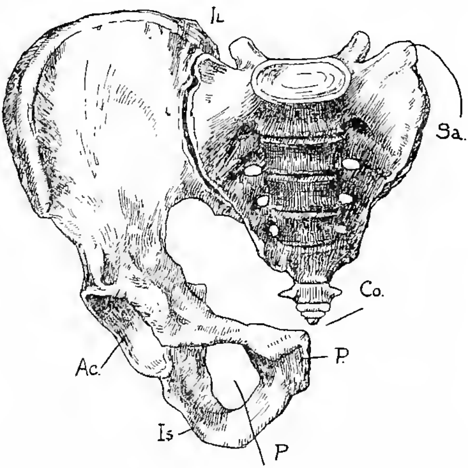

FIG. 22.—The right half of pelvic girdle and sacrum. *Il.* ilium; *Is.* ischium; *P.* pubis; *P* pointing to obturator foramen; *Sa.* sacrum; *Co.* coccyx; *Ac.* acetabulum cavity.

the general direction of the bone; the lower end is converted into a pair of condyles, which rest on the tibia.

THE PATELLA OR KNEE-CAP.—The patella comes just in front of the femur and above the tibia; it is shaped like the shell of the limpet, and is held in position by a ligament. It protects and limits the movement of the knee joint.

THE LEG.—The leg extends from the knee to the ankle, and is made up of two bones, the **tibia** and

fibula. The tibia or shin bone is long and roughly triangular in shape. In its upper surface there are a pair of oval depressions, into which the condyles at the lower end of the femur rest, and between which there is a groove in which the patella works. The lower end of

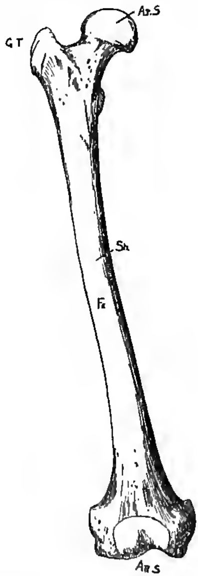

FIG. 23.—The right human femur. *Ar.S.* articular head of femur; *G.T.* great trochanter; *Sh.* shaft of femur; *Ar.S.* lower surface, which articulates with top of tibia and patella.

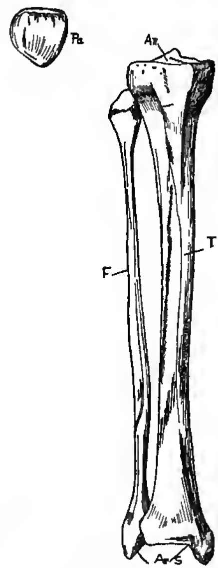

FIG. 24.—The tibia and fibula. *T.* tibia; *Ar.* articulating surface for union with the lower end of femur; *F.* fibula; *Ar.S.* articulating surface for union with astragalus at ankle; *Pa.* patella.

the tibia is concave, and it rests on the convex surface of the astragalus. The fibula or splint bone is fixed at the outer side of tibia, to which it is connected at both ends, but its lower end extends below the ankle joint, to which it offers protection. It is a long but slender bone, which helps to strengthen the leg.

THE ANKLE.—The ankle is made up of seven tarsal bones, which are arranged in two rows; the first consists of three bones, and the row up to the metatarsal of four bones. The tibia rests on the convex surface of the astragalus, and the heel is formed by

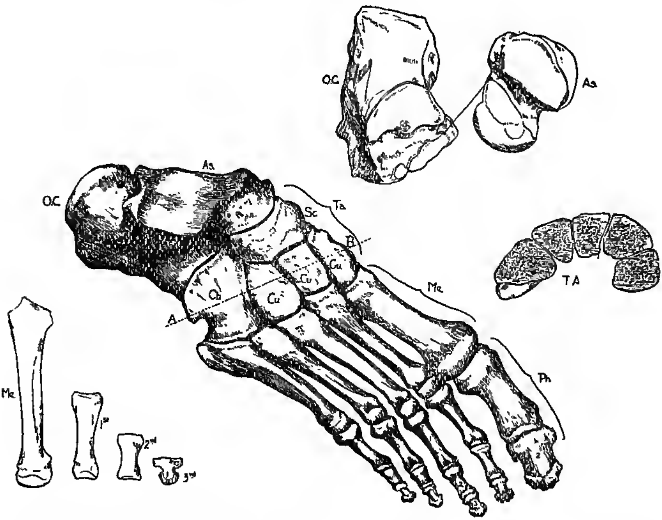

FIG. 25.—Diagram of the right foot. *O.C.* calcaneum; *As.* astragalus; *Cb.* cuboid; *Sc.* scaphoid bone; *Cu. Cu. Cu.* the three cuneiform bones; *Ta.* Tarsal bones; *A*,*B*, line of axis; *Ma.* metatarsals; *Ph.* phalanges; *OC.* calcaneum separated from astragalus, *As.*; *TA.* section of arch of foot. The figure on the left shows the metatarsal and the three phalanges of toe.

the calcaneum, which offers support to the astragalus. In front of the astragalus comes the scaphoid bone (Fig. 25, *Sc.*). Just between the calcaneum and instep and on the outer edge of the foot there is the cuboid bone, while in front of the scaphoid there are three cuneiform bones.

THE INSTEP.—The instep is made up of five metatarsal bones, which can be compared to the five

metacarpal bones of the palm of the hand. They are long bones, but diminish in size from the inner to the outer side.

THE DIGITS OR TOES.—The five digits are made up of fourteen phalanges; the big toe consists of two, and the other four toes of three each.

SUMMARY OF STRUCTURE OF GIRDLES AND LIMBS

Division.	Names of Bones.	Characters of.	Attachments.
Pectoral girdle.	Scapula or shoulder blade.	A triangular-shaped bone, which contains the glenoid cavity.	It is fastened with ligaments to the thorax, and unites with the clavicle, while the humerus articulates with the glenoid cavity.
	Clavicle or collar bone.	A slender bone with slightly enlarged ends.	The clavicle articulates with the scapula and sternum, and helps to support the former.
Arm.	Humerus.	A long bone with upper end rounded, and lower forming a pulley-like surface.	It articulates with the glenoid cavity of scapula, and to ulna and radius at elbow.
Forearm.	Ulna and radius.	Long bones. Radius with upper end small and rounded, and lower end wide. Ulna with upper olecranon process and socket for humerus, and bone small and rounded.	The ulna unites with the lower end of humerus, and its movement is limited with the olecranon process. The lower end can rotate on the radius. The radius carries the hand, and the upper portion can rotate on the ulna.

SUMMARY OF STRUCTURE OF GIRDLES AND LIMBS—*continued*

Division.	Names of Bones.	Characters of.	Attachments.
The wrist.	Eight carpal bones.	Small irregular-shaped bones, which are arranged in two rows.	The upper row articulates with the radius, and the lower with the five metacarpals.
The palm of hand.	Five metacarpal bones.	Small cylindrical bones with irregular - shaped ends.	They articulate with a row of carpal bones, and with five phalanges.
The digits or fingers.	Fourteen phalanges.	Bones of various length, but cylindrical in shape. 2, 3, 3, 3, 3.	The first row articulates with the metacarpals, and with one another.
The pelvic girdle.	The ilium, ischium, and pubis.	The bones are fused to form the os innominatum or hip bone.	The two os innominata are connected to the sacrum by means of sacral ribs and ligaments. Each contains an acetabulum cavity in which the head of femur rests.
The thigh.	The femur.	The long bone with head forming nearly a right angle, and a pair of condyles at lower end, which rest on tibia.	It articulates with the acetabulum cavity of hip bone, and with the tibia.
The leg.	The tibia or shin bone, and fibula or splint bone.	Long bones. The tibia is a strong bone with enlarged upper end, which contains depressions in which the lower end of femur rests. The fibula runs from the knee to ankle, and is a long slender bone.	The tibia articulates with the femur above, and ankle below. The fibula is united to the tibia above, and articulates with the tibia and tarsal bone below.

SUMMARY OF STRUCTURE OF GIRDLES AND LIMBS—*continued*

Division.	Names of Bones.	Characters of.	Attachments.
The knee.	The patella.	A somewhat rounded bone, which is shaped like a shell.	Articulates with the top of tibia, and lower end of femur.
The ankle.	Seven tarsal bones.	The astragalus, calcaneum, scaphoid, cuboid, and three cuneiform bones.	The astragalus articulates with the lower end of tibia, and with the calcaneum, which forms the heel. Between the astragalus and cuboid comes the scaphoid, while in front is a row of three cuneiform bones.
The instep.	Five metatarsal bones.	They are long bones, which vary in length.	Unite with the cuneiform bones and first row of phalanges.
The digits.	Fourteen phalanges.	Slender long bones. 2, 3, 3, 3, 3.	The first row articulates with the metacarpals, and with other phalanges.

QUESTIONS FOR REVISION

1. Show by means of a drawing the position of the scapula and clavicle.
2. How is the humerus connected to the pectoral girdle, and the latter to the thorax?
3. Give a sketch of the right arm, forearm, and hand. Enumerate the bones which enter into the structure of the above organs.
4. Write a short account of the shapes and relative positions of the bones of the upper limb.
5. What structures enter into the composition of the pelvic girdle?

6. How is the pelvic girdle connected to the vertebral column?
7. Describe the form and position of the femur.
8. Give an account of the shape, position, and uses of the patella or knee-cap.
9. Write a short account of the forms and relative positions of the bones in the lower limb.
10. Give a brief description of the structure of the human foot.
11. Sketch and describe the following bones—astragalus, calcaneum, patella, fibula.
12. How does the pelvic girdle differ from and resemble the pectoral girdle?

CHAPTER V

JOINTS

The bones which form the skeleton articulate with one another to form joints. A perfect or movable joint is formed when two or more bones meet, and they are so arranged that a certain amount of movement can take place. An imperfect or nearly immovable joint is formed when the bones articulate at the edges by means of cartilage, and little or no movement is possible. We will now proceed to examine the structure of the joints formed in the human body.

THE GENERAL STRUCTURE OF A JOINT

Experiment 10.—(1) Obtain from a butcher a sheep's foot, and examine a joint in the following manner: (i) Open one of the joints with a knife, and examine the interior. The surfaces of the bone where they meet are tipped with cartilage (Experiment 2), which is hyaline in nature, and gives perfectly smooth surfaces. (ii) The bones are adapted by shape to move over each other, and the cartilage reduces the friction. (iii) Note the strong cords or ligaments which unite the bones. Stretch one; it is slightly elastic. The interposition of slightly elastic cartilage and ligaments between the movable bones enables shocks to be received and confers mobility. (iv) Examine the articular surfaces, and note that their shape will allow movements

to be made in certain directions, but imposes certain limits in other directions.

(2) Carefully remove from the outside of another joint the mass of external tissue until a well-defined layer of slightly elastic tissue or **capsule** is seen. This binds the bones together, and makes the joint air-tight. Remove this, and similar structures to those already examined will be exposed to view.

(3) Note the fine membrane which lines the interior of the capsule, the **synovial membrane**. This secretes the synovial fluid, which is of an oily nature, and which lubricates the structures in the joint. Small pads of tissue may be present in the joint, each of which is surrounded by synovial membrane, the function of which is to reduce friction within the joint.

THE STRUCTURES FOUND IN JOINTS.—There are several structures which may be present in joints. Each joint consists of two or more bones which have specially-shaped ends, and these are tipped with cartilage to give a firm but smooth and elastic surface. The outside of the joint is formed of a sheet of strong fibrous tissue which forms a **capsule**, thus giving an air-tight joint. The interior of this is lined with a **synovial membrane,** which secretes **synovial fluid.** This keeps the joint structures lubricated. The heads of the bones are held in position by ligaments. In some joints there are small pads of tissue, which are covered with synovial membrane, and these reduce friction. Such pads form **bursæ.**

SUMMARY OF STRUCTURES IN A JOINT.—(1) There is the sheet of fibrous tissue which forms a capsule round the ends of the bones, and holds them in position.

(2) The synovial membrane which lines the capsule, and secretes the synovial fluid which lubricates the joint structures.

(3) The bones are tipped with cartilage.

(4) The ligaments inside the joint which bind the bones together.

(5) The bursæ which may be present in the joint.

Experiment 11.—(1) Obtain from a butcher a piece of the great neck ligament of an ox. Select a small

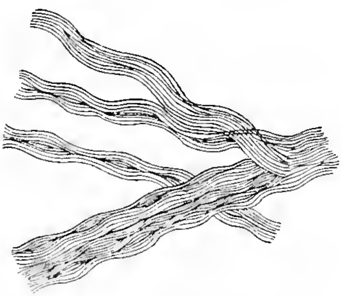

FIG. 26.—White fibres from tendon.

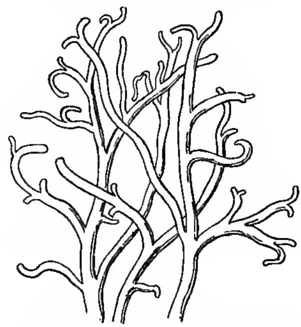

FIG. 27.—Yellow elastic fibres from yellow fibro-connective tissue.

piece, and lay it on a glass slide in a drop of salt solution. Now tease or separate the fibres by means of needles or pins (p. 12). Examine with a low power, then with a high power, and find the fibres. (i) Some of these are yellowish in colour, wavy, may curl up, branch and join each other. These are known as yellow elastic fibres, and their presence in ligaments gives a certain amount of elasticity to them. (ii) Bundles of straight white fibres, which cross in all directions and are elastic. (iii) Cells may be seen between the fibres, and these may branch.

(2) Remove from just beneath the skin of a freshly-killed rabbit a piece of the very fine transparent tissue which joins the skin to the muscles beneath. Spread it on a dry glass slide, and add a drop of salt solution. Cover. Examine and find (i) the white fibres which cross in all directions; (ii) the connective tissue cells or corpuscles, which either lie on or between the fibres.

THE STRUCTURE OF CONNECTIVE TISSUE.—The tissue which binds the whole of the structures of the body together is known as **connective tissue.** If a piece of suet is examined and unrolled, the fine membrane in which the fat is deposited is connective tissue; this and the fat, forming **adipose tissue**. There are several kinds of connective tissue. These are:—

1. **Yellow fibro-connective tissue,** which is composed of yellow elastic fibres, a few white inelastic fibres, and connective tissue cells; found in ligaments.
2. **White fibro-connective tissue,** which consists principally of white inelastic fibres and cells; found in tendons.
3. **Areolar tissue,** which is a mixture of the above in different proportions; found sheathing the blood vessels.

PERFECT OR MOVABLE JOINTS PRESENT IN THE HUMAN BODY

The joints in which movements can take place are divided into five classes. These are:—

1. Ball-and-socket joints $\left\{\begin{array}{l}\text{Shallow.}\\ \text{Deep.}\end{array}\right.$
2. Hinge joints.
3. Gliding joints.
4. Saddle joints.
5. Pivot joints.

BALL-AND-SOCKET JOINTS.—In a ball-and-socket joint, the head of one bone is rounded, and fits into a socket in another bone (Fig. 29). The bone with the rounded head can be made to rotate if the cavity be shallow. This is well illustrated by the humerus, which can be moved round within the shallow glenoid cavity, with which it forms a shallow ball-and-socket joint. The femur rests within the deep

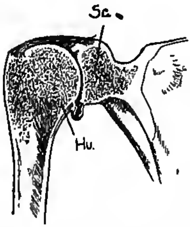

FIG. 28.—Diagram showing articulation of the humerus; *Hu.* with the glenoid cavity of scapula, *Sc.*

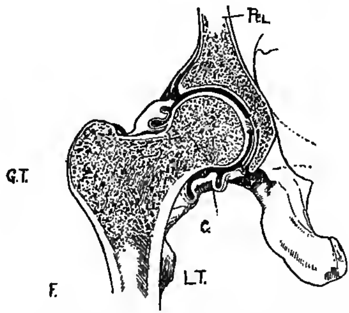

FIG. 29.—Longitudinal section through the hip joint. *Pel.* pelvic girdle (os innominatum); *F.* femur; *G.T.* great trochanter; *L.T.* lesser trochanter; *C.* capsule. Note the ligaments inside the joint and the head of femur in the acetabulum cavity.

acetabulum cavity of the hip bone, and can *not* be rotated as freely as the humerus.

HINGE JOINTS.—A hinge joint is formed when one bone possesses a locking process which allows movements similar to those of a door. The forearm can be moved through an angle of about 180 degrees. The movement is limited by the **olecranon process** at the end of the ulna. The knee, ankle, wrist, and fingers illustrate this type of joint.

GLIDING JOINTS.—The carpal bones of the wrist are lubricated with synovial fluid, and their shape permits a little movement. The clavicle can move slightly where it joins the sternum. They form gliding joints.

SADDLE JOINTS.—One bone in a saddle joint has a surface shaped like a saddle, or is convex, and the other surface which rests on this is concave. The metacarpal bone of the thumb rests over the convex

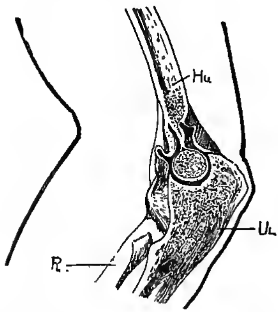

FIG. 30.—Longitudinal section through the hinge joint at elbow. *Hu.* humerus; *Ul.* ulna; *R.* radius. Note the position of the olecranon process on end of ulna.

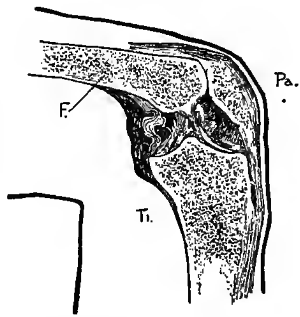

FIG. 31.—Longitudinal section through the knee joint. *F.* femur; *Ti.* tibia; *Pa.* patella supported in its ligament.

surface of its carpal bone, forming a saddle joint. The concave surface of the atlas rests on the saddle-shaped axis to form a similar joint.

PIVOT JOINTS.—The atlas can rotate round the **odontoid process** of the axis, so that the head can move through an angle of slightly more than 180 degrees, but further movement is prevented by a ligament. This is a pivot joint. The radius which carries the hand can cross the ulna. It is possible to turn

the hand over while holding the elbow, and the pivot which allows this movement is formed by the upper end of radius.

Experiment 12.—Use the following table, and make out on an articulated skeleton and on your own body the position and structure of the joints enumerated. Move the bones of the skeleton, and compare the movements observed with those which the various parts of the living body can make. Note any contrivances which may be present for limiting the movements.

THE JOINTS FOUND IN THE ARM, FOREARM, AND HAND

Place.	Kind of Joint.	Bones which form Joint.
Shoulder.	Shallow ball-and-socket.	Head of humerus and shallow glenoid cavity of scapula.
Elbow.	Hinge.	Lower end of humerus and upper end of ulna. Movements limited by olecranon process on ulna.
Wrist.	Hinge.	Lower ends of radius and ulna with first row of carpal bones.
Forearm.	Pivot.	The radius crosses the ulna.
Fingers, or four digits.	Hinge.	Phalanges with four metacarpals, and phalanges with phalanges.
Thumb.	Saddle joint.	Metacarpal of thumb with carpal bone, phalange with metacarpal, and phalange with phalange.

THE JOINTS FOUND IN THIGH, LEG, AND FOOT

Place.	Kind of Joint.	Bones which form Joint.
Hip.	Deep ball-and-socket.	Head of femur and deep acetabulum cavity of hip bone.
Knee.	Hinge.	Lower end of femur, top of tibia and patella.
Ankle.	Hinge.	Lower end of tibia with the astragalus.
Toes.	Hinge.	First row of phalanges with metatarsal bones, and phalanges with phalanges.

OTHER JOINTS

Place.	Kind of Joint.	Bones which form Joint.
Head.	Hinge.	Condyles on skull which rest in depression of atlas.
Head.	Saddle.	Concave surface of atlas on convex surface of axis.
Head.	Pivot.	Movements of atlas round odontoid peg of axis.
Lower jaw.	Hinge.	Condyles of lower jaw which fit into cavities of squamosal bones.

IMPERFECT JOINTS.—The vertebræ have between them (p. 32) pads or intervertebral discs of cartilage, and these and the vertebræ are united by ligaments. The pads of cartilage allow of a certain amount of movement between the vertebræ, and this is the reason why the vertebral column is flexible. The bones of the skull articulate together by a locking arrangement which form sutures, and the periosteum passes across the sutures, binding the bones together. The joints between the vertebræ only allow a very small amount of movement and form imperfect joints, while those between the bones of cranium can be said to be immovable.

QUESTIONS FOR REVISION

1. What is a joint? What structures may be present in a joint?
2. Enumerate the kinds of joints found in the upper limb.
3. Describe, with examples, the structure of ball-and-socket joints.
4. Define ligament, connective tissue, bursa, areolar tissue.
5. How does a hinge joint differ from a ball-and-socket joint? Give examples.
6. What is a saddle joint? Give examples.
7. Explain what movements the head can make, and describe the structure of the parts you mention.
8. Give illustrations of the articulation of the femur with the tibia, the humerus with the ulna, and the tibia with the astragalus.
9. What is a pivot joint? Give examples.
10. Enumerate the joints which are known as imperfect.
11. What movement can the hand make when the elbow rests on the table?
12. Describe the movements which the foot can make, and why.
13. What is meant by synovial fluid, and of what service is it?
14. Define cartilage, capsule, synovial membrane, and articular surface.

CHAPTER VI

THE MOVEMENT OF BONES

NEARLY all the movements of the body are due to the contraction of skeleton muscles, which act on bones, and these are controlled by the nervous system. In Chapter V. we noticed how the bones were articulated to form joints, and that these were adapted for movements. We will now consider the structure and properties of the muscles which move the bones.

SKELETON MUSCLES.—The muscle which bends the forearm is known as the biceps, and it may be taken as typical of this class of structures. The centre is the thickest portion, and is known as the **belly** (Fig. 33); from this point it tapers in both directions, and the lower end is connected to the periosteum of the radius by a tendon, while the upper end divides into two branches, which end in a similar manner in the scapula.

It is covered with a sheath, the **epimysium,** and is divided into a number of bundles. Each bundle is enclosed in a sheath, the **perimysium,** and contains numerous fibres. The fibres are bound together with connective tissue, which form sheaths, the **endomysium.** The place where the muscle is fixed so that the greatest amount of movement can take place is known as the **point of insertion,** and where the least movement, the **point of origin.** The ends of the biceps where they are fixed to the scapula represent the latter, and the

former is represented by its insertion in the radius. A muscle fibre is about $1\frac{1}{4}$ inches in length and the $\frac{1}{400}$ of an inch wide. It tapers like the muscle, or is shaped like a spindle. A fine membrane, the **sarcolemma,** encloses the **muscle substance,** which is **striated.** The endomysium carries blood-vessels and lymphatics for its

FIG. 32.—The biceps muscle when relaxed. *a*, tendon of muscle; *b*, point of insertion; *R*, point of origin; *S*, scapula; *M*, belly of muscle.

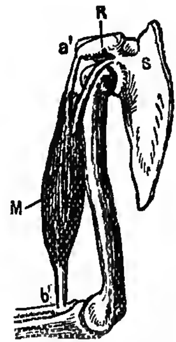

FIG. 33.—The biceps muscle when contracted. Lettering the same as in Fig. 32.

nourishment, and the nerve fibres which bring nervous impulses from the central nervous system.

Experiment 13.—Obtain a dead rabbit, and dissect the muscles of the right fore-leg. (1) Find the origin of the biceps on the scapula, and insertion in the periosteum or membrane covering the bone of the radius. The point where the muscles move the bones the least is known as their origin, and the place where they move the most is the point of insertion. Bend the forearm,

and find the points of origin and insertion. Illustrate this with a sketch. (2) In a similar manner find the origin of the triceps, which arises by three heads from the pectoral girdle and humerus, and its insertion in the olecranon process of the ulna. Work the forearm, and note that the actions of the biceps and triceps are antagonistic. (3) Work your own arm, and find the biceps and triceps. Compare these with those of the rabbit. (4) Note the shape of the biceps. It is the thickest in the centre, and tapers towards the ends. A membrane or sheath covers it, and the ends of the muscle are fixed by tendons to the periosteum of the bones.

Experiment 14.—(1) Remove the smallest possible strip from the muscle of a dead frog or rabbit which has been kept in methylated spirits. Tease out in glycerine with needles, so as to separate the fibres. Cover and examine. Note (i) The alternating dim and bright cross-bands, which extend throughout the length of the fibres. (ii) Alter the focus of the microscope; the dim and bright bands appear to change places.

(2) Remove the whole of the muscle from the leg of a dead fly or cockroach. Tease as before and mount. Examine and note that the striations are more distinct.

CONTRACTION OF MUSCLES.—The living healthy muscle possesses the important property of **contractibility** or of changing its length. If the biceps contracts, it shortens, and at its point of insertion pulls the radius nearer to the arm. Thus the property of contractibility enables movements of the limbs to be made. Several changes occur in muscles during contraction.

(1) **The Muscle changes its Shape.**—The shortening of the muscle produces a corresponding change

in thickness, and what it loses in length it gains in diameter. It shortens from 80 to 65 per cent. of its length during contraction. On relaxation the muscle regains its original position and shape.

(2) **The Muscle becomes Acid.**—A resting muscle is either neutral or alkaline; but the contracting muscle is acid; this is due to the production of **sarcolactic acid** from the muscle substance, which changes into carbon dioxide and water.

(3) **Heat is produced in the Muscle.**—The increased supply of oxygen produces more oxidation with its corresponding heat, but the circulation of the blood through the muscle distributes it so that its temperature remains fairly constant.

MOVEMENTS OF A LIMB.—The forearm can be bent or **flexed**, and the biceps is the **flexor muscle.** It can be **extended** or straightened by the triceps, which is the **extensor muscle.** The limb can also be **abducted** or moved away from a middle line by **abductor muscles,** and adductored or moved towards the sternum by **adductor muscles.**

Experiment 15.—(1) Bend your forearm so that it touches the humerus, and note that the contraction of the biceps causes the flexion of the forearm. When a limb bends, it is said to be flexed, and the muscles which do this are known as **flexors.** Thus the biceps is a flexor muscle. (2) Straighten the forearm so that it is in a line with the humerus; this is caused by the contraction of the triceps muscle. When a limb straightens, it is said to be extended, or **extension** has taken place, and the muscles which bring this about receive the name of extensors. (3) Bring the right arm into such a position that the fingers can touch the

breast-bone. Now remove it so that it is held in a direct line with the scapula. It is said to be abducted, and the muscles which do this are known as **abductors.** (4) In a similar manner bring the arm back so that the fingers once more touch the front wall of the chest. The muscles which do this receive the name of the **adductors,** and the movement is one of adduction.

LEVERS.—The muscles act on bones which form levers, and it is by the action of levers that the movement of walking, grasping, nodding, and eating are carried out. In poking a fire the poker rests on a bar; this point is known as the **fulcrum**; the coal which has to be lifted is the resistance to be overcome or the **weight,** and the **power** is applied at the end which is in the hand. In mechanics there are three orders of levers, and this is also true of the body.

Order of Lever.	Arrangement of.	Example.	Example in the Body.
First.	The fulcrum between the weight and power.	The poker and a pair of scissors.	The head resting on the atlas, which is the fulcrum; the power is applied by the muscles of back or front, and the weight is the head.
Second.	The weight comes between the fulcrum and power.	A wheel-barrow, nut-crackers, and treadle of sewing machine.	The foot when on tiptoe. The fulcrum is where the toes touch the ground, the power is applied at the heel, while the weight rests on the ankle.
Third.	The power comes between the fulcrum and weight.	A pair of fire-tongs and sugar-tongs.	The forearm when flexed. The forearm is the weight, the fulcrum is at elbow, and the biceps applies the power at point of insertion in radius.

QUESTIONS FOR REVISION

1. Give an account of the shape, position, and union of the biceps muscle.
2. About how big is a muscle fibre of one of your own muscles? Describe its structure.
3. How would you proceed to make a preparation of striated muscle for examination with the microscope?
4. Define sarcolemma, muscle substance, belly, and epimysium.
5. What changes take place in a muscle when it contracts?
6. Define flexion, extension, adducted, abducted.
7. What is a lever? Give an account of the different orders of levers, illustrating your answer by examples from the human body.

CHAPTER VII

THE BLOOD

The blood is the red fluid which circulates through the blood-vessels, and it consists of a liquid portion, the plasma, in which numerous red and colourless corpuscles float. By means of the blood all the organs in the body are intimately connected. It distributes oxygen and nutritive materials to the tissues, and collects waste substances, which are removed from it in the excretory organs, the lungs, skin, and kidneys.

THE COMMON CHARACTERS OF THE BLOOD

The blood possesses certain common characters. These are given below.

1. The blood is red, but the tint varies from bright scarlet in arterial to dark reddish purple in venous blood.

2. The blood is heavier than water, but the **specific gravity**, as this character is called, varies at 60° F. from 1055 to 1062. A cubic foot of water equals 1000 ounces, but a similar quantity of blood would weigh from 1055 to 1062 ounces.

3. The blood is not transparent, even in a thin layer, and is said to be **opaque**. This is due to the difference in the refractive powers of the plasma and the corpuscles, the result being an opaque fluid. If the plasma is separated from the corpuscles and examined,

it is transparent; so are the corpuscles. If whipped ~~blood is mixed~~ with water, the mixture forms laky blood, and this is transparent in thin layers.

4. The blood is alkaline, saltish, and warm. The average temperature is 98·4° F. (37° C.) in man, but it may have a slightly higher temperature in the deeper parts of the body.

THE PLASMA

We will now consider the composition and characters of the plasma.

Experiment 16.—(1) Half fill a jar with a saturated solution of sodium sulphate, and ask a butcher to fill up the bottle with fresh blood from the neck of a freshly-killed ox. Let it stand for twenty-four hours. The corpuscles sink to the bottom of the jar, and a clear yellowish fluid can be decanted off. This is a mixture of sodium sulphate solution and plasma, and the yellow colour is due to the plasma.

(2) Place a little in a test-tube, and boil. A solid is formed, due to the coagulation of the proteins in the plasma.

(3) Now dilute a little of the plasma with four or five times the quantity of warm water. The contents of the tube sets like jelly. Place it on the hand, and note its characters.

THE COMPOSITION OF PLASMA.—The plasma consists of water, in which a number of substances are dissolved. The composition is given below:—

Water	90 per cent.
Proteins	8 „
Fats, extractives, and salts	2 „
	100

THE PROTEINS IN PLASMA.—The plasma contains three proteins:—

Serum albumen.
Serum globulin.
Fibrinogen.

The above proteins are coagulated by heat, and fibrinogen aids in the clotting of the blood.

THE EXTRACTIVES AND SALTS OF PLASMA.—The substances which can be separated from the plasma are a little urea, uric acid, and creatine. These are organic nitrogenous bodies which are formed in the body due to the functions of life. In addition to the above, a little fat, sugar, and inorganic salts can be extracted from the blood.

The most abundant salt is common salt, and there are traces of other mineral salts.

THE CORPUSCLES

There are two kinds of corpuscles in human blood, viz., the red and colourless.

Experiment 17.—(1) Clean the tip of the long finger, and with a needle which has been passed through the Bunsen flame or flame of spirit lamp, prick the finger. Now remove the drop to a clean glass slide, and spread with a cover-glass. Care must be taken not to let the drop of blood touch the skin, for the sweat contains a considerable quantity of common salt, and this extracts water from and changes the shape of the corpuscles.

(2) Examine with a low power, noting the very numerous corpuscles. Now use the high power, and find a good field of vision, looking for the corpuscles. Note (i) the numerous red corpuscles which stick together and form long rows, like piles of coins. Those

which are seen on the flat are circular and have dark centres. In most preparations a few of the red corpuscles may appear dumbbell-shaped. This appearance is due to the corpuscles being seen sideways. (ii)

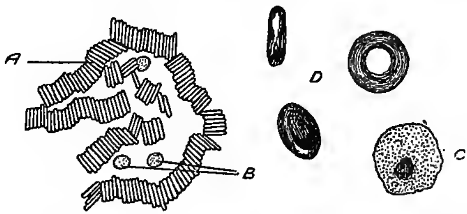

FIG. 34.—Human blood corpuscles. *A*, red corpuscles forming long rows or *rouleaux;* *B*, colourless corpuscles; *C*, a colourless corpuscle more highly magnified; *D*, red corpuscles seen in different positions. (× 400.)

The colourless corpuscles are a little larger and are not so numerous as the red ones.

Each colourless corpuscle contains granular matter, and one or more nuclei. When stationary it is nearly

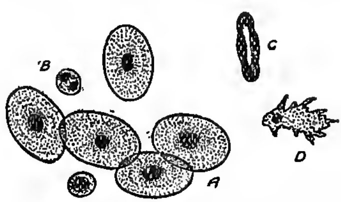

FIG. 35.—Corpuscles from frog's blood. *A*, red corpuscles with nuclei; *C*, red corpuscle as seen from the side; *B*, colourless corpuscle at rest; *D*, active colourless corpuscle. (× 400.)

circular in shape, but in the active condition can change its shape.

(3) Mix a drop of blood with a drop of water on a slide, and let it stand for half-an-hour. The colouring

matter (hæmoglobin) in the red corpuscle oozes out, and it may crystallise to form a number of crystals.

(4) Place two large drops of blood on a slide, cover and let it stand for twenty minutes. Examine the clotted blood, and note the fibres of fibrin which cross the field of vision in all directions.

THE CHARACTERS OF THE CORPUSCLES.—The following table gives the characters of the corpuscles of human blood.

THE RED CORPUSCLES	
Shape . .	Circular biconcave discs.
Size	The $\frac{1}{3200}$ of an inch in diameter, and the $\frac{1}{12000}$ of an inch in thickness.
Structure . . .	All parts of the corpuscle are alike in structure, or they are homogeneous.
Composition . .	Made up of a framework or stroma which holds a colouring matter, the hæmoglobin.
Comparative number	One colourless corpuscle to 500 red ones.
Function . . .	To carry oxygen from the lungs to all parts of the body.
THE COLOURLESS CORPUSCLES	
Shape . . .	No definite shape; can change shape while living.
Size	The $\frac{1}{2500}$ of au inch wide.
Structure . . .	Made up of protoplasm which contains one or more nuclei, and granular matter.
Composition . .	The protoplasm contains water, carbon, hydrogen, oxygen, nitrogen and sulphur; the nucleus contains phosphorus.
Functions . .	Destroy bacteria, and liberate pro-fibrin ferment.

HÆMOGLOBIN.—The red corpuscles owe their colour to a protein substance which is known as **hæmoglobin.** By appropriate means, the hæmoglobin can be split into two proteins—**globulin** and **hæmatin.** The latter contains iron in addition to carbon, hydrogen, oxygen and nitrogen, while the former contains sulphur along with the four elements enumerated above. The following compounds can be formed with hæmoglobin:—

Substances.	United with	Colour.	Where found.
Hæmoglobin.	Minimum amount of oxygen.	Reddish-purple.	Principally in venous blood.
Oxy-hæmoglobin.	Maximum amount of oxygen.	Scarlet.	Principally in arterial blood.
Carbon monoxide hæmoglobin.	Carbon monoxide.	Cherry-red.	In the blood during carbon monoxide poisoning.

The hæmoglobin in the red corpuscles, on passing through the lungs, unites with oxygen and changes into oxy-hæmoglobin. The latter gives up this loosely-united oxygen to the tissues in different parts of the body, and becomes hæmoglobin once more. It is always performing this work from birth to death, and upon this depends very largely the well-being of the human body. In performing this oxygen-carrying function, the red corpuscles wear out and die, while new ones, which are formed in the red marrow of the bones, take their place. The late Professor Draper calculated that some 150,000,000 would die and be born each minute.

BLOOD CLOTTING

The blood, while in contact with the living walls of the blood-vessels, remains in a liquid condition, but on

being withdrawn from their protective influence, begins to clot. The clotting of the blood results in the separation of its constituents into clot and serum. The former contains all the corpuscles and a fibrous substance which is known as fibrin, while the latter contains everything found in the plasma, except fibrinogen, which has been changed into fibrin. One of the most characteristic properties of the blood is that of clotting.

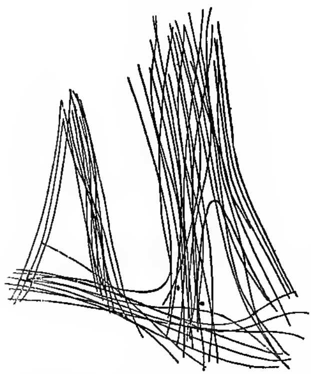

FIG. 36.—The network of fibrin which is left after the removal of the blood corpuscles.

Experiment 18.—(1) Now place a little of the salted blood obtained for Experiment 16 in a test-tube, and dilute it with four times its quantity of warm water. It sets or clots. Examine the clot, and notice its colour and general appearance. The water has diluted the sodium sulphate, so that clotting can take place.

(2) Request a butcher to fill a jar with the fresh-drawn blood of the ox, and let it stand until it sets like jelly, or **clots.** At the end of twenty-four hours examine the contents of the jar, and notice (i) the straw-coloured fluid in which the clot floats, the **serum.** (ii) Place a little of the serum in a test-tube; it is straw-coloured. Boil; a white opaque substance is formed—the proteins have been coagulated by the heat. (iii) Remove the clot from the serum, and place on a dish. The upper portion exposed to air is bright scarlet, but the rest of the clot is reddish-purple. Cut open the clot, and compare the appearance of the interior with the

exterior. (iv) Spread out a small piece of the clot on a glass slide, and examine with a low power. Look for the fibres of **fibrin,** which cross in all directions, and the corpuscles between the meshwork of fibres.

(3) Obtain from the butcher a ball of fibrin which has been obtained from some whipped blood, and notice (i) the red corpuscles, which cling to it. (ii) Wash some of the fibrin under a stream of running water; the corpuscles are removed, and a light-coloured fibrous substance will be seen. This is fibrin. (iii) Stretch some of the fibrin; it is elastic. (iv) Place a little in a test-tube, and hold over the Bunsen flame. It sets just like the proteins in the plasma and serum, and this shows that it is a protein substance.

(4) Now examine some fresh defibrinated or whipped blood, and note that it contains everything found in the blood except the elements of fibrin. (i) Place some in a test-tube. It is bright scarlet. This is due to the mixing of air with the blood during the whipping process, which has changed the hæmoglobin into oxy-hæmoglobin. (ii) The whipped blood is opaque, and even in a thin layer printed matter cannot be read through it. (iii) Dilute a little with some water, and let it stand for some time. Now examine the laky blood. Printed matter can be distinctly seen. This is due to the hæmoglobin leaving the corpuscles, which forms a homogeneous fluid.

The blood as it flows from a living blood-vessel into a bowl is a liquid, but in the course of from four to about ten minutes it sets like jelly, and if allowed to stand for from twenty-four to forty-eight hours separates into clot and serum. If the blood clots very slowly, a buffy coat is formed on the upper surface of the clot. This is due to most of the red corpuscles sinking from the upper portion of the blood, and the

clot in that portion being formed of fibrin and colourless corpuscles. The upper portion of the clot is often cup-shaped. This is due to the fibrin meeting with very little resistance on shrinking, as many of the red corpuscles have sunk down to a lower layer.

CAUSE OF BLOOD CLOTTING.—The colourless corpuscles, when they leave the blood-vessels, break up, and liberate pro-fibrin ferment. This unites with calcium salt, which is present in the plasma, and forms fibrin ferment. The fibrin ferment acts on the fibrinogen, and splits it into fibrin and globulin. The former is the cause of the blood clotting; the latter remains in solution in the serum.

The fibrin entangles the corpuscles within its network, and as the fibrin shrinks, due to its elasticity, the serum is squeezed out, while the corpuscles remain along with the fibrin in the clot.

THE SERUM.—The serum is a straw-coloured fluid which differs very little in composition from the plasma. The differences and resemblances are shown below.

Serum.	*Plasma.*
Straw colour.	Straw colour.
Contains serum albumen.	Contains serum albumen.
" serum globulin.	" serum globulin.
" fibrin ferment.	" fibrinogen.
" salts and extractives.	" salts and extractives.
Will not clot.	Will clot.

THE USES OF BLOOD.—The blood—

1. Receives oxygen in the lungs, and distributes it to the tissues.

2. Collects nutritive material from the alimentary canal, and carries them to the different structures of the body.

3. Collects from the tissues waste materials, which are removed by the lungs, kidneys, and skin.

4. Receives heat from the muscles, glands, and nervous centres, distributing it, and so equalising the temperature of the body.

SUMMARY OF THE BLOOD.—The following gives the general composition and substances present in the blood :—

- Blood
  - Plasma
    - Water, 90 per cent.
    - Proteins, 8 per cent.
    - Extractives, &c., 2 per cent.
  - Corpuscles
    - Red
      - The dried corpuscle contains :—
        - Stroma or framework, 10 per cent.
        - Hæmoglobin, 90 per cent.
    - Colourless
      - Protoplasm.
      - Nucleus.
      - Water.
      - Extractives.

Blood on clotting is divided into clot and serum.

- Plasma
  - Serum.
  - Fibrin } Clot.
- Corpuscles } Clot.

QUESTIONS FOR REVISION

1. Describe the appearance of blood as seen with the microscope.
2. What are the common characters of human blood?
3. Give an account of the appearance, composition, and properties of plasma. How can plasma be obtained?
4. Write an account of the shape, size, structure and function of the red corpuscles of human blood.
5. How would you obtain and prepare a drop of blood for examination with the microscope?
6. Explain how the colouring matter can be extracted from the red corpuscles.
7. How do the colourless corpuscles differ from the red ones?

8. What is hæmoglobin? Of what service is hæmoglobin? Enumerate the different kinds of hæmoglobin.

9. Describe the changes which occur in freshly-drawn blood when allowed to stand in a basin for a few hours.

10. What is fibrin? How can fibrin be obtained for examination?

11. Give an account of the clotting of the blood. Of what service is the clotting of the blood?

12. What is the red colour of blood due to? Does the colour of blood change, and if so, when?

13. Define defibrinated blood, serum, plasma.

14. How does plasma differ from serum and from defibrinated blood?

CHAPTER VIII

THE CIRCULATORY SYSTEM

The circulatory system consists of all the organs which have to do with the circulation of the blood throughout the body. The centre and force pump of this system is the heart, which forces the blood through a series of closed tubes, the arteries, capillaries, and veins. The arteries are strong vessels, which receive blood from the heart and distribute it to the capillaries, which have thin walls through which substances can ooze into the surrounding lymph. The blood is collected from the capillaries by small veins; these discharge into larger veins, which return the blood to the heart. We will now proceed to study the structure and functions of the above organs in detail.

DISSECTION OF THE SHEEP'S HEART

Experiment 19.—Obtain a sheep's heart and lungs from a butcher, with the bag in perfect condition.[1]

(1) Carefully examine and note that the heart is enclosed in a membranous bag, which is known as the pericardium, the lower portion of which is united to the diaphragm in the living animal, and it is reflected over and connected with the base of the great blood-vessels. The heart occupies the space between the

[1] The heart and lungs may be soaked in strong salt solution for twenty-four hours; this removes most of the blood, and makes the dissection much cleaner.

left and right lungs, and the pointed end is directed downwards and slightly towards the left.

(2) Examine the pericardium; a quantity of fat is generally deposited in the outer layer. Slit up the pericardium with a knife or a pair of scissors, and insert the finger into the opening; the layers are moist. The inner lining of cells secretes a fluid which is known as the

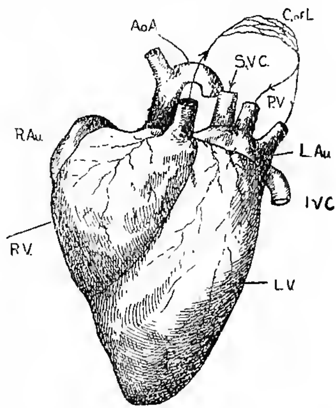

FIG. 37.—Front view of sheep's heart. *I.V.C.* inferior vena cava; *S.V.C.* superior vena cava; *R.Au.* portion of right auricle; *R.V.* right ventricle; *C. of L.* capillaries of lungs; *P.V.* the two pulmonary veins; *L.Au.* left auricle; *L.V.* left ventricle; *Ao.A.* aortic arch. The arrows mark the direction of flow of blood.

pericardial fluid. The outer layer of the pericardium is known as the **parietal layer**, and the inner one, which adheres to the walls of the heart, forms the **visceral layer.**

(3) Remove the parietal layer of the pericardium; the surface of the heart to which the visceral layer is attached will be exposed to view. Try and tear from the heart a small piece of this layer with a pair of forceps. It is very thin, and adheres very tightly to the muscular walls of the heart.

(4) The heart is reddish-brown, and down the front an oblique groove will be seen; this contains a quantity of fat. The front is more rounded than the back, and down the back there is a short, nearly straight groove which contains fat. Note the blood-vessels which arise from the base or broad end of the heart, and that the pointed end forms the apex.

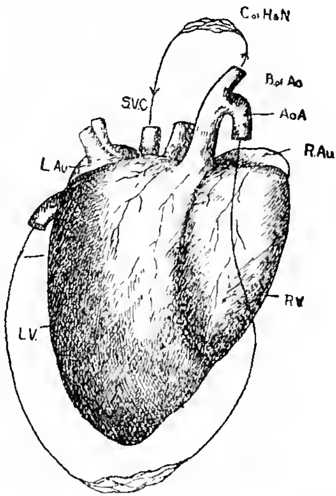

FIG. 38.—Back view of sheep's heart. *S.V.C.* superior vena cava; *R.Au.* right auricle; *R.V.* right ventricle; *L.Au.* left auricle; *L.V.* left ventricle; *Ao.A.* aortic arch; *B. of Ao.* branch of aortic arch, which supplies the capillaries of head and neck, *C. of H. and N.* The lower set of capillaries are the systemic ones.

(5) Find the left side of the heart. This can be done by placing the heart with the oblique groove upwards and the base towards you; the portion of the heart towards the left hand will be the left side. Feel the left side of the heart, and note that the lower portion is thick and firm. In a similar manner examine the right side; it is soft and flabby.

(6) Mark on the outside of the heart the boundaries of the different parts. These are (i) The upper portion of the heart on the left side is known as the **left auricle,** and a lower cavity forms the **left ventricle.** The corner of the auricle is prolonged into an ear-like flap, the **appendix.** The walls of the left ventricle are thick and firm, but those of the auricle are thin and soft. (ii) In a similar manner the right side of the heart is divided into a **right auricle** and a **right ventricle.** The cavity of the right auricle is prolonged into an ear-like flap, the **appendix,** and its walls are just a little thinner than those of the left auricle. The walls of the right ventricle are softer and thinner than those of the left ventricle.

(7) Cut the heart away from the lungs, leaving a good length of blood-vessels. Now find the different blood-vessels. (i) The one in front, and near the middle line of the base, is the **pulmonary artery.** It is white and thick-walled, and being elastic can be stretched. Pass a pencil down the vessel; it enters the right ventricle. (ii) The one just behind the pulmonary artery, and to the right of it, is the **aorta.** It is also white, elastic, and thick-walled. Pass a pencil down the aorta; it enters the cavity of the left ventricle. The pulmonary artery and the aorta are the largest arteries in the body, and they carry blood from the heart. (iii) Examine the base of the right auricle, and find the opening of a thin-walled vein, which enters the top of the auricle, the **superior vena cava.** It is thin-walled, blue, and inelastic. Pass a pencil through the vessel into the cavity of the right auricle, and move it about until it can be passed out at the opening of the **inferior vena cava.** The inferior vena cava opens into the right auricle at a lower level than the superior vena cava. The superior vena cava

brings blood from the upper portion of the body into the right auricle, and the inferior vena cava brings blood from the lower portion of the body to the same cavity. (iv) Examine the outer surface of the left auricle, and find the two pulmonary veins which bring blood from the lungs. They are thin-walled, blue, and inelastic. The veins, which we have just examined, bring venous blood to the auricles.

(8) Pass your pencil through the superior vena cava and out at the inferior vena cava; now cut along the pencil so as to lay open the cavity of the right ventricle. (i) Examine and note the thin muscular walls, and that they are composed of bands of muscle which intersect in all directions. The smooth layer of endocardium which lines the auricle reduces the friction to a minimum. The cavity of the auricle is said to be quadrilateral; confirm this. (ii) Remove a portion of the wall with a pair of scissors; note the opening into the right ventricle. Pour some water into the ventricle and squeeze it; the three flaps of the tricuspid valve are floated up, and the outline of the junction can be clearly seen. By applying pressure to the walls of the ventricle the water is forced out at the pulmonary artery.

(9) Cut a triangular flap out of the wall of the right ventricle; this can be done by passing the point of the scissors through the wall on the right side of the oblique groove of fat, cutting downwards and outwards; now fold back the flap. Note the thickness of the wall as compared with that of the right auricle. (i) Remove the front wall of the ventricle and examine the interior. Find the three flaps of the **tricuspid valve,** which guards the opening between the auricle and ventricle. These are fixed to the fibrous ring, as the edge of the plate of fibrous tissue which comes between the auricle and ventricle is called. The free

edges of the flaps are connected to **chordæ tendineæ,** and these are fixed by the opposite ends to **papillary muscles,** as the muscular projection of the inner walls of ventricle are called. (ii) Note the **moderator band**; this is a fleshy band, which crosses the cavity of the ventricle and transmits impulses from the right auricle

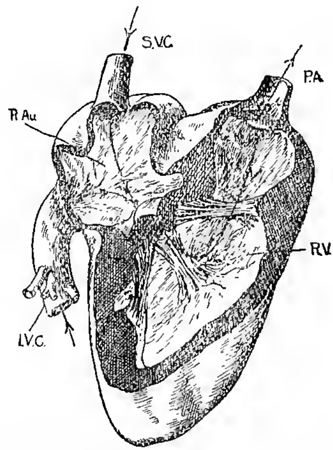

FIG. 39.—Dissection of right side of sheep's heart. *I.V.C.* inferior vena cava; *S.V.C.* superior vena cava; *R.Au.* right auricle; *R.V.* wall of right ventricle; *P.A.* pulmonary artery. The arrows show the direction in which the blood moves.

to the apex of the heart. It is only found in Ungulates, such as the sheep and ox.

(10) Pass the pencil along the pulmonary artery, and with a pair of scissors open the artery. Find at the junction of the right ventricle and the artery the **pulmonary semilunar valves.** These consist of three pocket-shaped valves, the openings of which point away from the ventricle. Place the pencil behind one pocket, and note (i) the small hard nodule of

cartilage, the **corpus Arantii**; (ii) the cavities behind the three valves, the **Sinuses of Valsalva.**

(11) Lay open the cavity of the left auricle, and note the thickness of its walls as compared with those of the right auricle. They are slightly thicker, and the interior is smoother. The shape of the cavity is roughly quadrangular, and it is lined with endocardium.

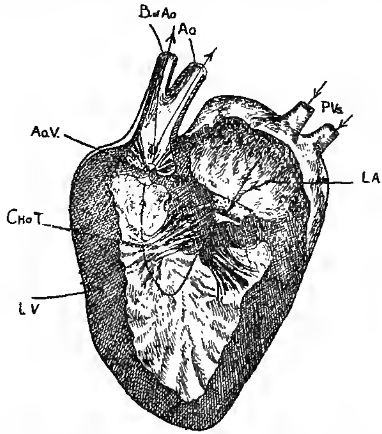

FIG. 40.—Dissection of left side of sheep's heart. *P.Vs.* pulmonary veins; *L.A.* left auricle; *L.V.* wall of left ventricle; *Cho.T.* chordæ tendineæ, joining the papillary muscles and mitral valve; *Ao.V.* aortic semilunar valves; *Ao.* aorta; *B. of Ao.* branch of aorta. The arrows show the direction in which the blood moves.

The walls are composed of bands of muscle, which intersect like those in the right auricle. Pour a little water into the cavity of the left ventricle and squeeze its walls; the **bicuspid** or **mitral valve** will be floated up. Note its appearance, and that it is fixed to the fibrous ring.

(12) Remove the front of the left ventricle. Compare the thickness of its walls with those of the right ventricle. The walls are three times as thick, and the

papillary muscles are much larger. (i) Find the two flaps of the mitral valve, and the annular ring formed by their union. Note their appearance, how they are fixed, and compare their structure with that of the tricuspid valve. (ii) Note the chordæ tendineæ, and their junction with the papillary muscles and flaps of the mitral valve. The cavity of the ventricle is smooth and lined with endocardium.

(13) Pass the pencil along the aorta, and open that vessel with a pair of scissors. Find the pocket-shaped **aortic semilunar valves.** Note the well-developed **corpus Arantii** and the large **Sinuses of Valsalva,** which are behind the pockets. Two small openings will be seen in two of the sinuses; these are the openings of the **coronary arteries,** which supply the substance of the heart with blood.

Experiment 20.—Obtain a fresh sheep's heart and lungs. Now remove the heart and a good length of the blood-vessels. (i) Fix into the superior vena cava a length of $\frac{1}{4}$-inch glass tube, and fasten with a piece of tape. Close the opening of the inferior vena cava, and ligature with a piece of tape. Pour water into the glass tube and squeeze the walls of right ventricle; some of the water will pass along the pulmonary artery. (ii) Fix in the pulmonary artery a long $\frac{1}{4}$-inch glass tube, and ligature as before. Pour more water into the tube, which is fixed in the vena cava, and imitate the beat of the ventricle by squeezing its walls; the water will rise in the tube fastened in the pulmonary artery, and the column of water will rest upon and be supported by the pulmonary semilunar valves. This experiment shows that the tricuspid and pulmonary semilunar valves prevent the backward flow of water, or in the living body blood, and that the

latter can only move from auricle to ventricle, and onwards to the artery. (iii) Repeat the experiment on the left side of the heart.

Experiment 21.—Carefully cut transverse sections of the heart used in the last experiment of the sheep (i) at the junction of the auricles and ventricles; (ii) between the apex and previous section. Note in the first section the pulmonary artery in front and the

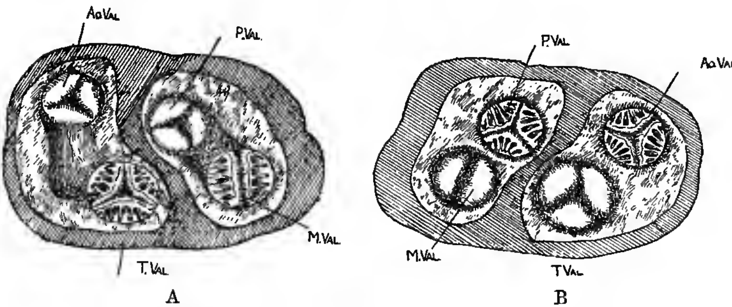

FIG. 41.—Transverse section of heart at junction of auricles and ventricles. A, as seen from above; B, from below. *T.Val.* tricuspid valve; *M.Val.* mitral valve; *Ao.Val.* aortic semilunar valves; *P.Val.* pulmonary semilunar valves.

aorta behind, and the cavities of the ventricles in one section and the auricles in the other piece. In the second section look at the shape of the cavities, the thickness of the walls, and the nature of the interior of the cavities. Sketch and describe.

THE STRUCTURE OF THE HUMAN HEART

The heart consists of four chambers; the upper ones are auricles and the lower ones ventricles, and a septum separates the blood in the two sides of the heart. In this way a double circulation is set up, one through the

lungs from the right side, and another from the left side throughout the general system. The heart of the sheep is a good example of a mammalian heart, and that of man only differs from it in some minor details. The human heart weighs from 9 to 10 ounces, and is about 5 inches long by 3½ inches wide, and 2½ inches

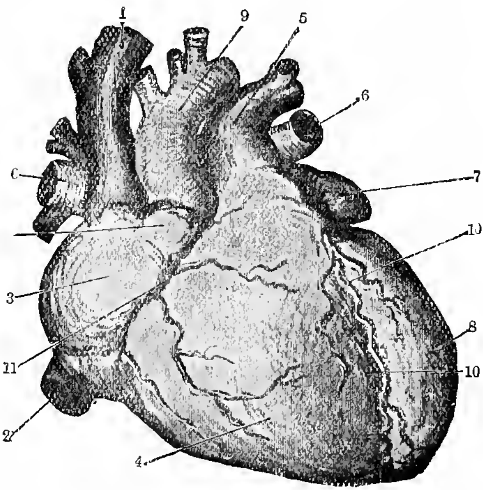

FIG. 42.—Front view of human heart. 1, superior vena cava; 2, inferior vena cava; 3, right auricle; 4, right ventricle; 5, pulmonary artery; 6, pulmonary veins; 7, appendix of left auricle; 8, left ventricle; 9, aorta; 10, groove filled with fat, which marks the septum between right and left ventricles; 11, groove showing division between right auricle and right ventricle.

in thickness. Each cavity will hold from 3 to 4 ounces of blood, and each time the left ventricle contracts that quantity of blood is forced into the aorta. The normal heart of an adult beats 72 times per minute, but in a young child from 120 to 140, while in an old person 65 will be the average.

THE RIGHT SIDE OF THE HUMAN HEART.—The right auricle receives venous blood from the general system by the superior vena cava and inferior vena cava, and it occupies the right side of the base of the heart. A fold of skin offers partial protection to the opening of the inferior vena cava, which is known as the **Eustachian valve.** Its walls are composed of a thin layer of cardiac muscle, and the cavity is lined with endocardium. One corner of the right auricle forms the appendix, and the coronary veins enter the right auricle.

The walls of the right ventricle form much of the anterior surface of the heart and a portion of the posterior surface; in fact, they form the right margin of the heart. Its walls are thicker than those of the auricle, and it is also made of cardiac muscle. The interior of the cavity is lined with endocardium; muscular projections on its interior walls form the papillary muscles. Between the right auricle and the right ventricle there is a valve which is made up of three flaps, the **tricuspid valve.** The bases of the flaps are connected together to form a circular membrane, which is fixed at the junction of the two cavities to the fibrous ring; the free edges of the valve are connected to the chordæ tendineæ. The pulmonary artery arises from the cavity of the right ventricle, and its opening is protected by three pocket-shaped valves, the **pulmonary semilunar valves,** which are fixed to the fibrous ring at junction of artery and ventricles. At the back of the semilunar valves there are three depressions, the **Sinuses of Valsalva.**

LEFT SIDE OF HEART.—The left auricle receives in man four pulmonary veins, and these bring blood from the lungs. It occupies the left side and part of

the posterior surface of the base of the heart, and the only portion which can be seen from the front is the appendix. The cavity is roughly quadrilateral, and its inner walls are smoother and a little thicker than those of the right auricle. The opening from the auricle into the right ventricle is oval and smaller than that of the right side.

The left ventricle is found at the apex and at the

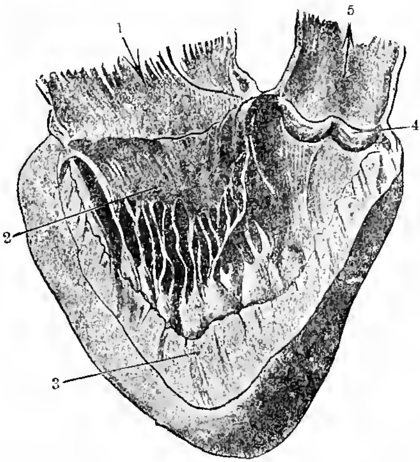

FIG. 43.—Dissection of the left side of human heart, showing 1, wall of left auricle; 2, one flap of mitral valve fixed to fibrous ring and connected to papillary muscles by chordæ tendineæ; 3, wall of left ventricle; 4, two aortic semilunar valves; 5, wall of aorta.

posterior portion of the heart. Its walls are about three times as thick as those of the right side, and its cavity is quadrilateral. A series of muscular projections, the papillary muscles, stand out from the interior walls, and to which the chordæ tendineæ are fixed. Between the left auricle and left ventricle there is a valve, the **mitral valve.** This consists of two flaps,

which are united at the base to form a circular membrane, which is fixed to the fibrous ring and the free edges to the chordæ tendineæ. The opening of the aorta is near to that from the auricle, and its opening is guarded by three pocket-shaped bodies, the **semilunar valves**, which are fixed to the fibrous ring at the junction of ventricle and artery. The work performed by the valves is to prevent the backward flow of blood from ventricle to auricle, and from aorta to ventricle (p. 92). The valves on the left side are thicker than those on the right side.

THE GENERAL STRUCTURE OF THE BLOOD-VESSELS

The blood during its passage through the body is propelled from the ventricles to the auricles by the contraction of the heart, and it moves through a series of passages which are known as arteries, capillaries, and veins.

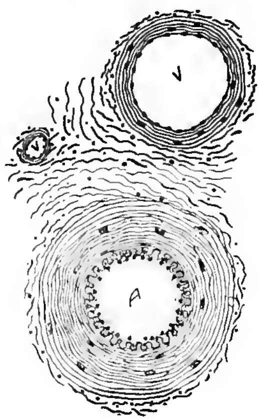

FIG. 44.—Transverse section of artery and vein. *A*, lumen of artery; *V*, lumen of vein.

THE ARTERIES. — The vessels which carry blood from the heart and supply it to the capillaries are known as arteries. In the dead body they are generally empty, and from this peculiarity the older physiologists gave them the name of air-tubes. The arteries are white, thick-walled, very elastic, and open when empty. An artery consists of three coats; these are: (i) An outer coat of areolar tissue,

which contains a considerable quantity of elastic fibres, which run lengthwise. (ii) A middle coat of muscular tissue, in which a number of elastic fibres run lengthwise. (iii) An inner coat made up of a thin layer of muscle, which is in contact with the middle coat, and beneath this a layer of very fine connective tissue, which is lined with endothelial cells. The internal layer of endothelial cells makes the interior of the tube very smooth, and this reduces friction to the minimum.

THE CAPILLARIES.—A capillary is a small tubular opening in connective tissue which is supplied

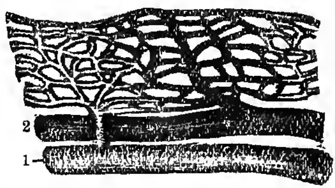

FIG. 45.—Diagram of a capillary system. 1, small artery which supplies the capillaries with blood; 2, small vein which collects the blood from the capillaries.

with blood by a small artery. The wall of the capillary consists of a number of endothelial cells, which are generally cemented together by cement material. In a very small capillary a single cell may form the wall; this is bent until the edges meet, and a small quantity of cement unites them together. Thus the width of such a vessel is less than the width of an endothelial cell, and their average width can be said to be the $\frac{1}{3000}$ of an inch. The thickness of the wall equals the thickness of an endothelial cell, and, because it is so thin, substances can pass through into the lymph spaces which surround the capillary. The principal property of a capillary is its extreme permeability, and

due to this the blood, in passing through such a vessel, gives up nutritive materials to and receives waste materials from the lymph.

THE VEINS.—The vessels which collect blood from the capillaries and bring it to the auricles are known as veins. Veins are blue, thin-walled, and inelastic. Each vein consists of (i) An outer coat of areolar tissue, in which white fibro-connective tissue predominates. (ii) A middle coat made up of a thin layer of muscle and with a few elastic fibres. (iii) An

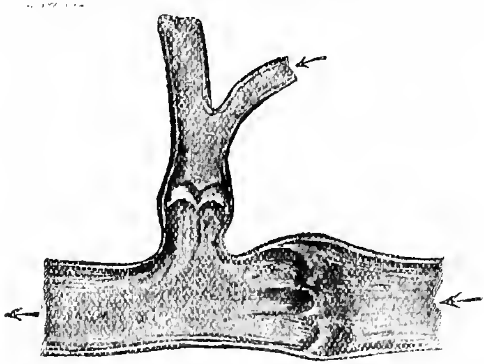

FIG. 46.—Diagram to show the arrangement of the valves in veins. The arrows mark the direction of the blood flow.

internal coat of fine connective tissue, which is lined with a layer of endothelial cells.

The veins of the legs and arms possess valves. These are folds of the connective tissue which forms part of the internal coat, and they are pocket-shaped like the semilunar valves of the heart. In a small vein a single valve may be present, but in larger ones as many as four may be present across the vessel. The veins of the bones, viscera, brain, spinal cord, and membranes of the nervous system have no valves.

Experiment 22. — 1. Examine the aorta from the sheep's heart, used in Experiment 20, and determine: (i) The **elasticity** of its walls; this can be done by stretching it, when it rebounds on being released. (ii) The thickness of its walls, which enable it to remain open when empty, and that it is circular in shape. (iii) Make out the three coats which form its walls, and the distinct white colour.

2. In a similar manner examine the structure and properties of the vena cava. Note (i) The inelastic nature of its walls. (ii) The thin walls, which are blue in colour. (iii) The closed lumen when empty, and the three coats of which its walls are built up.

3. If a preparation can be obtained of an artery and a vein, examine it with the low power, and find the following parts: (i) the outer coat of areolar tissue (Fig. 44), in both the artery and a vein, and compare their thickness; (ii) the middle coat of muscular tissue in both the artery and vein, and look for elastic fibres, which run lengthwise. Compare the thickness of this coat in the above vessels. (iii) The internal coat of fine connective tissue, which is lined with endothelial cells, and compare thickness and structure in the artery and vein. (iv) Compare shape and size. In most cases the lumen of the vein is just a little larger than that in the artery; while the artery is circular in shape, the vein may have lost its circular shape due to pressure.

QUESTIONS FOR REVISION

1. Give an account of the position, shape, size, and appearance of the sheep's heart.

2. How can you distinguish the front from the back of the sheep's heart, the base from the apex, and the left side from the right?

3. Describe carefully the form, position, nature of, and use of the mitral valve.

4. Define the terms pericardium, chordæ tendineæ, and pericardial fluid.

5. Write an account of the structure of the left side of the sheep's heart, and compare with the right side.

6. Enumerate the valves of the heart.

7. How does the tricuspid valve differ from the mitral valve, and the wall of the left ventricle from the wall of the right ventricle?

8. Where would you look for the aortic semilunar valves in a sheep's heart? Describe their structure.

9. Define corpus Arantii, sinuses of Valsalva, and coronary artery, moderator band.

10. How does the human heart differ from the sheep's heart?

11. Describe the structure of a capillary system. How do arteries differ in structure from veins and from capillaries?

12. Give a brief account of the circulatory system.

CHAPTER IX

THE CIRCULATORY SYSTEM—*Continued*

THE CARDIAC MUSCLE.—The heart is composed of a peculiar kind of muscle tissue which is known as cardiac muscle, and which is found in the walls of the heart, and extends for a short distance into the bases of the great veins. Each fibre is in reality a cell which possesses a nucleus. It is striated, and without sarcolemma. Between the fibres a little cement material is deposited. This binds a number of fibres together to form a bundle, and a number of bundles are joined together by connective tissue which carries blood-vessels, nerves, and lymphatic vessels. It differs from the muscles which move the bones in having no sarcolemma, in shape, and in function. Cardiac muscle possesses the power of rhythmical contraction apart from the action of the nervous system.

Experiment 23.—Place a small piece of the ventricular wall of the sheep's heart in a 40 per cent. solution of caustic potash for fifteen minutes. Now tease out a very small piece with pins in a drop of the above solution, and examine with a low power. Note the cardiac fibres or cells. Each fibre contains a nucleus, and it possesses striations, but it is not surrounded by a sarcolemma. Some of the fibres may have processes by which they dovetail together. The caustic potash dissolves the cement which unites or cements the fibres together, and this enables them to be easily separated.

THE CARDIAC CYCLE.—The cardiac cycle consists of all the events which take place in one complete beat of the heart, and it occupies on an average $\frac{8}{10}$ of a second. The contraction of the heart or of any of its chambers is known as **systole**, and relaxation as **diastole.** The auricles contract or are in systole together, and then the ventricles. In a similar manner the auricles are in diastole together, and so are the ventricles. The auricles contract in a sudden and very rapid manner, the wave of contraction commencing at the base of the great veins, and this spreads over the auricles. Shortly after the systole of the auricles ceases, the ventricles contract, the wave commencing at the apex and spreading over the whole of the walls. First the auricles pass into diastole, then the ventricles. The time taken by the systole of the auricles is only about $\frac{1}{8}$ of the total time of the beat of the heart, and they are in diastole about $\frac{7}{8}$ of the time of the beat. In the case of the ventricles the systole equals $\frac{3}{8}$ of a cardiac cycle, and the diastole $\frac{5}{8}$ (p. 94).

THE COURSE OF THE CIRCULATION OF THE BLOOD THROUGH THE HEART AND BODY.—The contraction of the heart drives the blood throughout the body, and it is usual to divide its movements into a number of separate systems. These are given below :—

1. The pulmonary or lesser circulation through the lungs.
2. The systemic or greater circulation through the general system.
3. The portal circulation through the liver.
4. The renal circulation through the kidneys.
5. The coronary circulation through the substance of the heart.

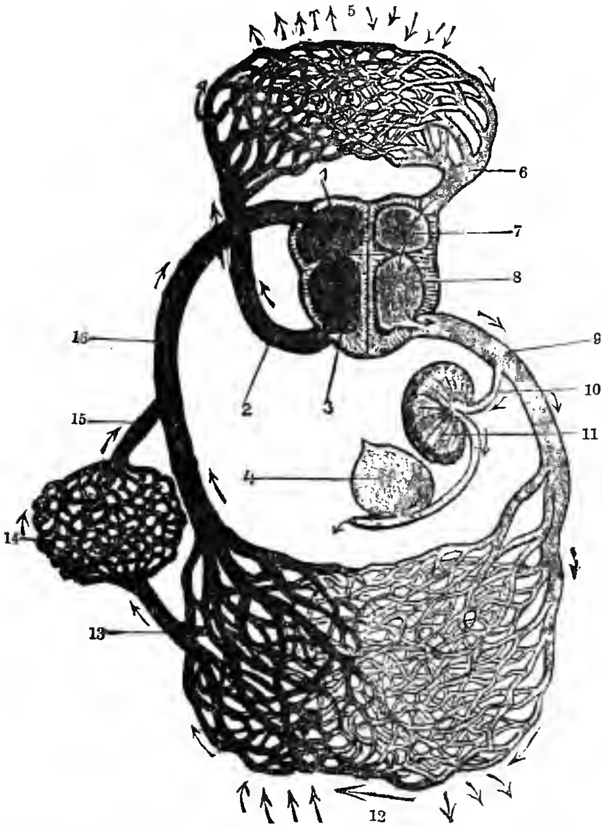

FIG. 47.—Diagram showing the circulation of blood in the body. The light-coloured portion contains arterial blood, and the darker portion venous blood. 1, right auricle; 3, right ventricle; 2, pulmonary artery; 5, pulmonary circulation; 6, pulmonary veins; 7, left auricle; 8, left ventricle; 9, aorta; 10, renal vein; 11, kidney; 12, systemic circulation; 13, portal vein; 14, portal circulation in liver; 15, hepatic vein; 16, inferior vena cava; 4, bladder. The arrows show the direction of the blood stream.

We will now consider the course of the blood through the lungs and general system.

THE PULMONARY CIRCULATION.—The right auricle contracts and forces the blood through the auricular-ventricular orifice into the right ventricle. The blood floats up the flaps of the tricuspid valve across the orifice, and these are held in position by the action of the chordæ tendineæ and papillary muscles. The contraction of the muscular walls of ventricle produces pressure, and when this exceeds the pressure in the pulmonary artery, the pulmonary semilunar valves are forced open and the blood passes into the pulmonary artery. The backward rush of blood fills the pockets of the semilunar valves, and the orifice is closed. The position and action of the valves on the right side of the heart keeps the blood moving in one direction, and prevents the return of the blood from artery to ventricle, or from ventricle to auricle. The venous blood flows along the pulmonary artery to its branches, and these end in small arteries, which supply the capillaries in the lungs. The blood loses carbon dioxide and gains oxygen as it passes through the capillaries in the lungs, and the arterial blood, as it is called, is collected by small veins. These join to form larger veins, which finally end in the four pulmonary veins (in man), which empty the blood into the left auricle. The circulation of the blood from the right side of the heart across the lungs to the left auricle is known as the **pulmonary circulation.**

THE SYSTEMIC CIRCULATION.—The left auricle contracts, and forces the blood through the auricular-ventricular orifice into the left ventricle. The blood floats the flaps of the mitral valve across the orifice, and these are held in position by the action of the chordæ tendineæ and papillary muscles. The contraction of the muscular walls of the ventricle raises the

pressure in the cavity until it exceeds that in the aorta, and the pressure of the blood against the semilunar valves forces them open, the blood flowing into the aorta. The rebound of the blood fills the pockets of the semilunar valves which close the orifice, and this prevents the backward flow of blood into the left ventricle. The position and action of the valves keep the

FIG. 48.—Diagram showing the condition of venæ cavæ, right auricle, tricuspid valve, right ventricle, and pulmonary semilunar valves when the right ventricle is being filled with blood. *R.V.* wall of right auricle; *R.K.* wall of right ventricle. The arrows show the direction of blood flow from auricle to ventricle.

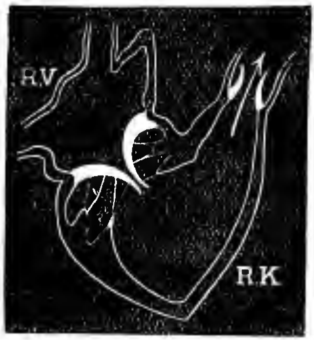

FIG. 49.—Diagram showing condition of the valves in the right side of the heart when the ventricle is being emptied. The arrow marks the direction of blood flow when the ventricle is being emptied. (Lettering as in Fig. 48.)

blood moving in one direction, and prevent the blood from returning from artery to ventricle, or from ventricle to auricle. The blood is distributed by the aorta to its branches, and these supply blood to very small arteries which end in capillaries. The blood which flows into the capillaries of the systemic system loses oxygen and nutritive materials, and gains carbon dioxide

and waste substances. This changes the arterial blood into venous. From the capillaries, small veins collect the blood, and these join to form larger veins, which empty into the inferior vena cava in the lower portion of the trunk, and superior vena cava in the upper portion of the trunk. These vessels empty their venous blood into the right auricle. The circulation of the blood from the left side of the heart through the general system to the right auricle is known as the **systemic circulation.**

The portal and renal circulation we will consider when we deal with the general structure of those organs, but we will now consider the coronary circulation.

THE CORONARY CIRCULATION.—Just where the aorta springs from the left ventricle, and behind the pockets of the semilunar valve in the sinuses of Valsalva, two small openings occur. These are the coronary arteries. The position occupied by these arteries shuts off much of the high pressure which exists in the aorta, especially when the left ventricle contracts and empties the extra quantity of blood into the aorta, which is always full. In addition, the contraction of the heart squeezes out the blood from the coronary vessels which are closed, and thus the nourishment of the cardiac fibres only takes place during diastole. The coronary arteries supply blood to the coronary capillaries, which run in the connective tissue which binds the bundles of cardiac muscles together, and this blood nourishes the walls of the heart. The blood is collected from the capillaries by coronary veins, which open directly into the cavity of the right auricle. The movement of the blood from the coronary arteries through the substance of the heart into coronary veins and right auricle is known as the **coronary circulation.**

The shortest course of the blood from the left side to the right side of the heart is through the coronary system.

THE CHARACTER OF THE FLOW OF BLOOD THROUGH THE BLOOD-VESSELS.—The blood, as we have seen, moves through arteries, capillaries, and veins. We will now consider the character of the blood-flow through these vessels. The aorta branches, and these enclose a greater amount of area than the

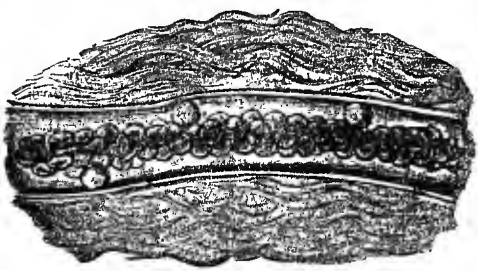

FIG. 50.—Diagram showing the flow of blood in a capillary. The red corpuscles move in the centre of the blood stream, while the colourless ones cling to the walls of the capillary.

original vessel. From this there arises an increased area in the small arteries for the blood to flow through, and the velocity of the blood decreases in its passage from the base of the aorta to the small arteries, for the same quantity of blood has to pass through the aorta that passes through thousands of small arteries, and in the same time. The immense number of capillaries still further increase the area through which the blood passes, and it has been calculated that the area of these vessels is some 700 times greater than that of the aorta. Thus the blood flows the slowest of all in the capillaries, and this is an important factor in the

circulation, for while passing through these thin-walled vessels, substances can ooze through the walls into the lymph. The small veins enclose a rather larger area than the corresponding small arteries, and the blood moves a little slower through the former vessels than through the latter. The small veins join to form larger veins, and these empty into two main trunks, the inferior and superior venæ cavæ. Thus the area through which the blood flows in the veins decreases, and the velocity of the blood increases from the small veins to the base of the venæ cavæ. The systemic circulation can be compared to a double cone, the base of the two cones being represented by the capillaries, and the apex of one cone by the base of aorta, and the other by the bases of the venæ cavæ. The blood moves very quick in the aorta, very slow in the capillaries, and at about half the speed in the venæ cavæ than in the aorta, because they enclose about double the area. This is shown below:—

The velocity of the blood in the aorta = about 15 inches per second.
The velocity of the blood in the capillaries = the $\frac{1}{50}$ to the $\frac{1}{70}$ of an inch per second.
The velocity of the blood in the venæ cavæ = about $7\frac{1}{2}$ inches per second.

BLOOD PRESSURE.—The blood in the left ventricle, as we have seen (p. 106), is at a higher pressure than that in the aorta. When this blood is forced into the aorta, which is always full of blood, its walls are put on the stretch through being distended, and pressure is stored up in its elastic walls. This pressure is known as **blood pressure,** and it plays a most important part in promoting the circulation of the blood throughout the systemic system. The blood flows from the left ventricle into the aorta in an intermittent

manner, and the force stored up in its walls converts this flow into a constant flow. This is due to the elastic walls squeezing the blood onward towards the small arteries, and as this is done in a fairly steady manner, the blood flows onward in a steady stream. Blood pressure falls slowly in the arteries, very suddenly in the capillaries, and still keeps falling in the veins until in the venæ cavæ it is almost nil. It is blood pressure which keeps the blood moving throughout the systemic system, and it is set up by the contraction of the walls of the left ventricle.

THE PULSE.—The contraction of the left ventricle forcing blood into full arteries not only produces blood pressure, but is the cause of the pulse.

Experiment 24.—Carefully place the first finger of the right hand about one inch from the wrist joint on the left hand, just over the radial artery. The pulse will be felt. Count the number of pulses in half a minute, when at rest, and after exercise. The pulse in the radial artery can be felt, because it runs just above the radius, and if pressed on it does not sink into soft tissue, but comes in contact with the bone. It is also easy to find.

The pulse wave is caused by the contraction of the walls of the left ventricle forcing blood into full arteries. This puts the elastic walls of the arteries on the stretch, and they vibrate. This vibration spreads over the walls of the arteries as a **pulse wave.** Thus the pulse is a wave motion passing over the wall of the arteries. The pulse is lost in the capillaries, and does not reappear in the veins except under exceptional circumstances. Each pulse in an artery represents a beat of the heart.

THE EVIDENCE OF THE CIRCULATION OBTAINABLE IN THE BODY.—There are several practical difficulties in proving that the blood circulates in the manner described above, but the following description will show what can be done in both the dead and living body to gain proofs of the circulation.

IN THE DEAD BODY

1. The structure of the heart as seen during dissection shows that the blood can only move in one direction, viz., from auricles to ventricles and from ventricles to arteries.

2. The existence of the two sets of blood-vessels, the arteries and veins, and the presence of valves in some of the veins, show that the blood can only move in the arteries away from the heart, and towards it in the veins.

IN THE LIVING BODY

3. If the hand is held downwards, and the veins are stroked towards the wrist, little swellings appear along the veins. This is due to the blood filling the pockets of the valves, and closing them to prevent a backward flow. This is a fairly good proof that the blood flows upwards in the arms towards the heart.

4. If a bandage is placed loosely round the arm above the elbow, the hand swells. This is due to the blood moving downwards in the arteries, which lie just a little deeper than the veins, and a loose bandage does not compress them, but prevents the flow in some of the veins. If the bandage is placed tightly from the first, the hand becomes pale and cold. This is due to the stoppage of the circulation of the blood.

5. If an artery is laid open in the living body, the blood spurts out with a considerable amount of force, but from a vein it comes out in a steady flow. It is the action of the pressure which is stored in the elastic wall of the artery which forces out the blood in a jet-like manner, and as the veins have little pressure stored up in their inelastic walls, the blood flows out in a steady stream.

6. The bleeding from a cut artery can be arrested by placing a bandage on the heart side of the cut, while that from the vein can be stopped by a similar bandage placed on the side of cut away from the heart. This seems to prove that the blood flows from the heart in the arteries, and towards it in the veins.

7. The circulation of the blood can be seen by the aid of the microscope in any transparent membrane, such as the web of a frog's foot, the tail of a tadpole or goldfish. This is the best and most conclusive proof of the circulation of the blood obtainable in the living body.

Experiment 25.—(1) Prepare a frog-board from the side of a cigar-box. This can be done by making a small hole about the centre of the board so as to fit over the aperture in the stage of microscope. Now wrap a frog in a damp cloth, leaving out one of the hind-legs; fasten the toes by means of pieces of cotton to pins fixed in the frog-board, so that the transparent web is over the central perforation. Fix the board by rubber bands to the stage of the microscope, and focus the low power on the web. Look for the blood-vessels and pigment spots. The high power can now be used, but a cover-glass should be placed between the web and object glass. Note (*a*) the blood moves out of comparatively large vessels into smaller ones. These

are arteries, and (*b*) through small vessels which discharge into larger ones. The former are capillaries, and the latter veins. Make a sketch to show the circulation of the blood through the above vessels.

THE REGULATION OF THE BEAT OF HEART.—The rhythmical contraction of the heart is due to the nature of the cardiac muscle, and not to the action of the nervous system. This is shown by the heart of a chick beginning to beat long before any nervous system is developed; and even the apex of the frog's heart is said to be without nerves, but it can contract if fed with serum when removed from the remainder of the heart. If the heart had no nerves and was not connected with the nervous system, it would probably beat always at the same rate. The requirements of the body under different conditions, such as when performing hard work or when asleep, do not always require the same amount of blood to pass through the capillaries. This is well illustrated by the action of the heart during sleep, for its beat is very slow, but during exercise it is much more rapid. The speed at which the heart contracts depends upon the action of—

1. The cardiac centre in the spinal bulb;
2. The cardiac branches of the vagus nerves;
3. The cardiac branches of the sympathetic nerves.

The cardiac centre is always generating impulses, which pass along the nerves enumerated above to the heart. The vagus is always bringing nervous impulses from the cardiac centre, which will make the heart go a little slower, while the sympathetic nerves bring nervous impulses, which increase the action of the heart. It seems certain that the cardiac centre is influenced by impulses which it receives from different

parts of the body, and this varies the impulses sent along the two nerves. Thus the beat of the heart is made to vary according to the requirements of the body.

THE REGULATION OF THE FLOW OF BLOOD THROUGH THE BODY.—Just as the requirements of the whole body for blood vary at different times and under different conditions, so the local requirements of the organs vary, and this is regulated by a special centre and nerves. These are—

1. A vaso-motor centre in the spinal bulb;
2. Vaso-motor nerves, which end in the muscular coat of the small arteries.

The vaso-motor centre generates nervous impulses within itself, and sends them out along the vaso-motor nerves. The vaso-motor nerves are always bringing impulses to the muscular coats of the small arteries, and when they come in an average way, the area of these vessels remains normal, due to the condition of the middle coat of arteries. The condition of the small arteries when in an intermediate condition is known as **vascular tone,** but this condition can be changed in two ways: (*a*) If the nervous impulses come a little quicker, the size of small arteries will be decreased. Pallor is due to this condition. (*b*) If the nervous impulses sent along the nerves come slower, the blood supply is increased; this is due to the muscular coat being dilated. Blushing is a well-known result of this condition.

QUESTIONS FOR REVISION

1. How would you proceed to examine a piece of cardiac muscle? Explain how a cardiac muscle fibre differs from a striated muscle fibre in structure and function.

2. What is meant by a cardiac cycle? How long does a cardiac cycle last, and into what parts can it be divided?

3. Describe the course of the blood through the heart and attached vessels.

4. Give an account of the coronary circulation.

5. How does the blood flow through arteries, capillaries, and veins, and why does it flow much slower in the capillaries than in either veins or arteries?

6. What is blood pressure? How is blood pressure produced, and what is its service to the body?

7. Describe the pulse. How is the pulse produced?

8. What evidence of the circulation can be obtained in (*a*) the dead body; (*b*) in the living body?

9. Why does the heart beat, and how is its beat regulated by the nervous system?

10. How is the flow of blood through the body regulated by the nervous system, and what is vascular tone?

11. What are the general resemblances and differences between arteries, capillaries, and veins as regards (*a*) their structure; (*b*) the flow of the blood which they contain?

CHAPTER X

THE LYMPHATIC SYSTEM AND DUCTLESS GLANDS

THE flow of the blood in the capillaries is very slow in comparison to that in the arteries (p. 108), and during its passage through the thin-walled capillaries a portion of the plasma oozes through into the spaces which surround these vessels, where it forms lymph. We have now to consider the characters of **lymph** and how it passes into the general circulation.

THE CHARACTERS OF LYMPH.—The lymph is a pale colourless fluid which bears certain resemblances to blood, but differs from it in various ways. Lymph is made up of water in which on an average 6 per cent. of proteins, salts, and extractives are dissolved. The proteins present in lymph are the same as those found in plasma, but the proportion is much less. This is probably due to the extreme difficulty with which these substances can diffuse through the membranous walls of the capillaries. The kinds and proportion of the salts in lymph do not differ from those found in blood, but it contains more waste materials. Its specific gravity is less than that of blood (1015), and when removed from contact with living matter it clots like blood. The clot is colourless, and not quite so solid as a blood clot. If the fluid is collected from the **thoracic duct** some time after the digestion of a meal containing fats, it presents a milky appearance. This is

due to the presence of numerous fat globules, which reflect the light. Such a fluid is known as **chyle.**

If lymph from the lymph spaces of the frog is examined with the microscope, a number of amœboid corpuscles will be seen. These are the lymph corpuscles or **lymphocytes.** They are smaller than the colourless corpuscles of the blood, and have large nuclei embedded in a small quantity of protoplasm. The lymphocytes enter the blood in the lymph, where they develop into colourless corpuscles.

Experiment 26.—Obtain a recently killed frog, and open the skin of the ventral surface, and mount a drop of the fluid from the large lymph space which will be exposed. Cover, and examine with the high power. Note (i) the colourless fluid in which numerous lymphocytes float. (ii) Make a detailed study of a single lymphocyte, and sketch the parts observed. (iii) Place the preparation on one side for half an hour so that it clots, and then examine for fibrin.

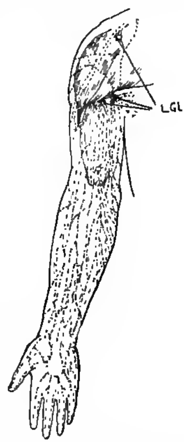

FIG. 51.—Diagram of lymphatics of arm and hand. *L.Gl.* lymphatic glands.

THE LYMPHATICS.—The lymph accumulates in the lymph spaces, which exist between the cells in connective tissue, and from these it oozes into lymph capillaries. These resemble blood capillaries in having thin walls, but are slightly larger, and the walls consist of cells which have crenate margins, by which they interlock. The lacteal radicals of the villi are lymph capillaries, and this is one of

the methods by which they originate. They may also commence in the lymph spaces in connective tissue, but, no matter what is their origin, they resemble one another in being connected with lymph vessels.

A lymph vessel is similar in structure to a small blood vein, but its wall contains more muscular tissue,

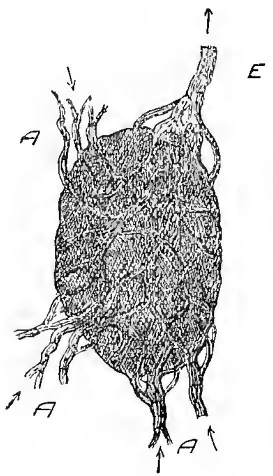

FIG. 52.—A lymphatic gland. *A.A.A.* afferent lymphatic vessels entering gland; *E.* efferent lymphatic vessel. The arrows show the direction in which the lymph moves.

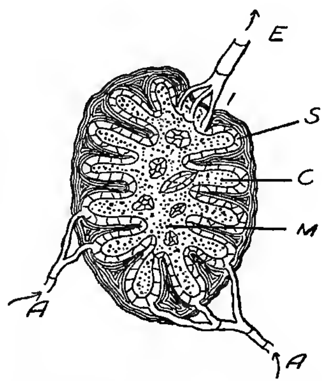

FIG. 53.—A diagrammatic section of lymphatic gland. *A.A.* afferent lymphatic vessels; *E.* efferent lymphatic vessel; *C.* cortical and *M.* medullary portion of gland; *S.* a lymph sinus.

and valves are more numerous. These prevent the backward flow of lymph. Lymphatic vessels are closely connected with small masses of adenoid tissue, which receive the name of lymphatic glands.

THE STRUCTURE OF LYMPHATIC GLANDS.—Each lymphatic gland is bean-shaped, and is surrounded by a capsule of connective tissue, which

contains a few plain muscle fibres. Afferent lymphatic vessels enter on the convex side of the gland, and efferent ones leave by the concave border. Blood-vessels also enter and leave the substances of the gland. From the capsule there projects into the interior of the gland a number of septa or partitions, and these divide the convex portion of the glandular substance into a number of alveoli. Each alveolus contains a quantity of adenoid tissue, in which there are numerous lymphocytes. The concave portion of the gland consists of numerous minute spaces, which are formed by the division and union of the septa (Fig. 53), and which contain blood-vessels and branches of the lymphatic vessels.

THE THORACIC DUCT.—On p. 19, we noticed that the thoracic duct is found in front of the vertebral column in the thorax, and that it was about as large as a quill-pen. It is a large lymphatic vessel, which is modified for the storing up of lymph. Its walls contain more muscular tissue, and the valves are more abundant than in an ordinary lymphatic vessel. It opens into the blood system at the junction of the subclavian and jugular veins of the left side of the neck.

THE MOVEMENTS OF LYMPH.—The lymph flows from the lymph spaces into the lymph capillaries, and from these into the afferent lymphatic vessels, which discharge into the lymphatic glands. The lymph undergoes certain changes in the glands, and there is an increase of lymphocytes as it flows through the efferent lymphatic vessels, which empty into the thoracic duct. From the latter the lymph enters the venous blood system on the left side of the neck at the junction of the subclavian and jugular

veins. The lymphatic vessels of the right side of head, neck, lung, and arm join the venous blood system on the right side at the junction of the subclavian and jugular veins.

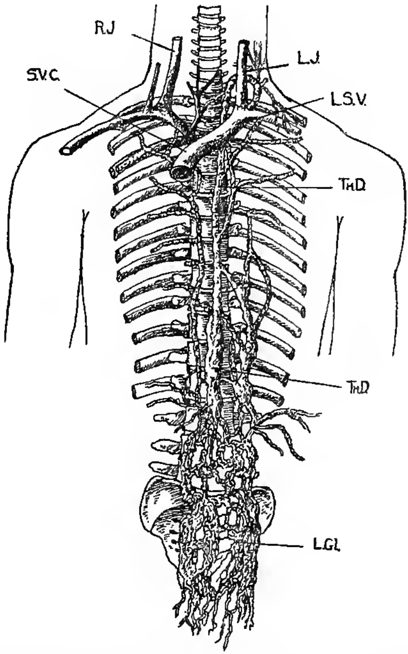

FIG. 54.—Diagram of the thoracic duct and attached vessels. *Th.D.*, *Th.D.* thoracic duct; *L.Gl.* lymphatic glands and vessels in mesenteric membrane; *L.S.V.* left subclavian vein; *L.J.* left jugular vein; *R.J.* right jugular; *S.V.C.* superior vena cava. Note the entrance of the thoracic duct at junction of left subclavian vein and left jugular vein.

THE CAUSE OF THE MOVEMENTS OF LYMPH.—In animals like the frog the lymph is made to move by the action of pulsatile vessels—the lymph

hearts—but such structures are absent in man. The causes of the flow of lymph in the body are—

(1) **Exercise.**—This causes the muscles to press on the lymphatic vessels, which forces the lymph onwards, and the presence of the valves prevents its backward flow.

(2) **Difference in Pressure.**—The lymph flows from the lymph spaces, where the pressure is the greatest, towards the great veins of the neck, where the pressure is the least. This promotes a steady onward flow of the lymph.

(3) **Respiratory Movements.**—During inspiration the pressure in the thorax is much reduced, and the end of the thoracic duct is protected by valves. The decreased pressure in the thorax sucks the blood from the great veins of the neck, and some of the lymph from the thoracic duct takes its place.

(4) **Contraction of Lymphatics.**—The layer of muscle which fits over the radical lacteals contracts and squeezes the lymph or chyle onwards, and the valves prevent its return. This has been seen to take place in some of the lower animals.

(5) **Osmosis.**—The passage of plasma from the capillaries into the lymph spaces aids the movement of the lymph.

USES OF LYMPH.—The lymph plays the part of middle-man between the blood in the capillaries and the tissues which it bathes; for it receives from the blood nutritive materials and oxygen, which it passes on to the elements of the tissues, receiving back waste materials, most of which find their way into the blood. In tissues, such as cartilage and the cornea of the eye,

in which blood-vessels are absent, this process is exaggerated, for the lymph carries the substances required for their nutrition a greater distance.

The lacteals, as the lymph capillaries of the villi are called, perform the important work of carrying the fats into the general circulation. The lymphatic glands are constantly at work forming lymphocytes, and these, entering the lymph, are conveyed into the blood stream. The lymph always passes during its circulation through a lymphatic gland, and we can assume that it is not fit to mix with the blood until it has undergone some changes in these structures.

THE DUCTLESS GLANDS

A number of glands exist in different parts of the body which have no **ducts** or tubes to remove any secretions which they may produce. These are known as **ductless glands.** Such glands seem to be closely connected with the circulatory system, and the substances which they form pass into the general blood stream. It is usual to define these substances as **internal secretions,** because they are not used in digestion, but enter the blood. Recently it has been discovered that **adrenalin,** which is secreted by the suprarenal glands, is necessary for the well-being of the sympathetic nervous system, and without it there is a fall of blood pressure. We will now consider the general structure of the ductless glands.

THE SPLEEN.—The spleen is held by a fold of the mesentery against the cardiac end of the stomach (Fig. 60), and it weighs about 6 ounces. In shape it is like the palm of the hand, and is nearly 5 inches in length and 4 in width. It is of a purple-red colour

and soft like a sponge. A well-defined capsule covers it, and a number of septa divide up the interior into a number of divisions, which contain spleen pulp. The spleen pulp is formed of cells, which branch, and the union of these produces a fine network, in which there is embedded **Malpighian corpuscles.** The spleen is constantly at work forming new colourless corpuscles of the blood and in removing worn-out red ones. Blood is brought from the aorta by the splenic artery and removed along the splenic vein, which is one of the factors of the portal vein. The spleen varies in size at different periods of the day, and reaches its maximum size a few hours after digestion.

THE THYROID GLAND.—The thyroid gland is found just below the larynx, and it consists of right and left lobes, which are joined by a small medium piece. It is covered with a capsule, and contains a number of sacs. Each sac is lined with cells, and these produce a secretion, which is clear and colloidal. Blood-vessels and lymphatics enter and leave the gland, so that its secretion passes into the blood and lymph. Its secretion is necessary for the proper development of the tissues, and in its absence the brain degenerates. If the gland is undeveloped in a child, a form of idiocy is produced, which is known as **cretinism.** During disease of the gland the skin becomes thick, the hair falls from the hair follicles, and the mind deteriorates. This can be remedied by using an extract of the thyroids of the sheep. This seems to show that its secretion is necessary for the health of the body.

THE THYMUS.—The thymus gland is the largest during infancy, and in adult life only exists in a rudimentary condition. It is placed just behind the

sternum, near the heart, and at birth is about one inch in length. It is formed of a number of lobules, and probably forms colourless corpuscles during infancy.

THE SUPRARENAL GLANDS.—On the top of each kidney there is a small gland, which is shaped like a three-cornered hat. The interior of the gland contains a medullary substance, which is surrounded by a cortical layer. The cells in the medullary portion secrete **adrenalin,** which is discharged into the blood, where it acts on the sympathetic system (p. 122).

QUESTIONS FOR REVISION

1. What is lymph? Where is lymph found, and how does it differ from (*a*) blood, (*b*) chyle?
2. Give an account of the composition and characters of lymph.
3. Explain how the lymphatics commence (*a*) in the arm, (*b*) in the intestine.
4. Describe the structure of a lymphatic gland. Where do lymphatic glands occur?
5. What is the thoracic duct, and what does it contain some time after the digestion of a meal of meat, bread, and potatoes?
6. Explain how the lymph enters the general blood stream.
7. Describe how and why the lymph moves through the lymphatic system.
8. What is the use of lymph?

CHAPTER XI

THE ALIMENTARY CANAL

THE muscular tube in which the food is digested receives the name of alimentary canal. It commences at the mouth and ends at the anus. From end to end it is lined with mucous membrane, and the secretions from numerous glands enter it to aid in the digestion

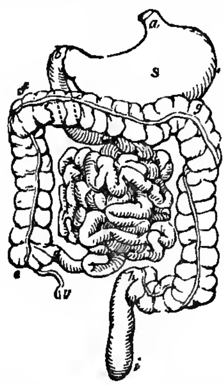

FIG. 55.—Abdominal portion of alimentary canal. *a*, œsophagus; *s*, stomach; *b*, commencement of duodenum; *d*, end of ileum; *c*, cæcum; *v*, vermiform appendix; *ef*, ascending colon; *fg*, transverse colon; *gh*, descending colon; *i*, end of rectum.

of the food. Some of the food which enters the alimentary canal is rendered soluble and diffusible, and the insoluble residue leaves by the rectum. The process by which food is made soluble, so that it will diffuse or pass through a membrane, is known as

digestion, and the passage of the food-stuffs into the blood and lymph, **absorption.** In this chapter we will consider the structure and arrangement of the alimentary canal. It consists of—

Mouth,
Pharynx,
Œsophagus,
Stomach,

Small intestine, which comprises	Duodenum, Jejunum, Ileum.
Large intestine, which comprises	Cæcum, Ascending colon, Transverse colon, Descending colon, Rectum.

THE MOUTH.—The cavity of the mouth is lined with mucous membrane, and it contains numerous small glands, which secrete mucus and saliva. The mucus and the saliva keep the lining of the mouth soft and moist. The roof of the mouth is formed by the hard and soft palates, the floor by the tongue and lower submaxillary bones and structures between, the sides by the cheeks, gums, and teeth, the front by the lips and teeth.

THE TEETH.—In man there are two sets of teeth developed, and in numerous cases a third set is obtained for a consideration at the dentist's. The first set are known as the milk or temporary set, and the second as the permanent set. In the milk set there are three kinds of teeth, and they number twenty—ten

in the upper jaw and ten in the lower jaw. The numbers of these are shown below, and the approximate time of cutting :—

Incisors .	. 8,	generally cut	at the	age of	six months.
Canine .	. 4,	"	by	"	eighteen months.
Milk molars	4,	"	"	"	twelve months.
	4,	"	"	"	twenty-four months.
	20				

From the above table it will be seen that a child two years old should have cut all the twenty teeth of

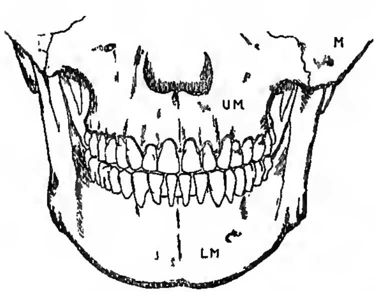

FIG. 56.—Diagram to show jaws and permanent teeth. *U.M.* upper maxillary bone; *L.M.* lower maxillary bone. Note the position of the teeth.

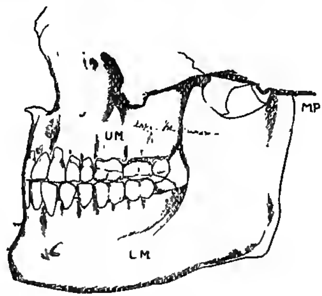

FIG. 57.—View of left side of face, showing the position of the teeth. Letters as in Fig. 56.

the milk set, and the exact arrangement of these will be seen from the following table :—

		Middle line of mouth.					
Upper jaw . .	2	1	2 ↓ 2	1	2	=10	=20
Name of teeth .	Molars	Canine	Incisors	Canine	Molars		
Lower jaw . .	2	1	2 ↑ 2	1	2	=10	

The milk set is replaced by the permanent set, which numbers thirty-two teeth. The following gives the

names and approximate time of cutting of the different teeth in the permanent set :—

Incisors . .	8	Central ones cut during the seventh year of life. Lateral ones cut during the eighth year of life.
Canine . .	4	Cut during the eleventh year of life.
Bicuspids .	8	Inner ones cut during the ninth year of life. Outer ones cut during the tenth year of life.
True molars	12	First molars, next to bicuspids, cut during the sixth year of life. Second molars cut during the twelfth year of life. Outer molars, or wisdom teeth, cut from the seventeenth to twenty-fifth year of life.

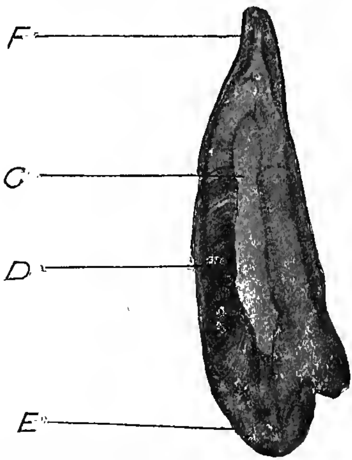

FIG. 58.—Longitudinal section of permanent human canine tooth. *F.* cement which covers the fang; *C.* pulp cavity; *D.* dentine; *E.* Enamel of crown. (Photomicrograph by Flatters, Milborne & M'Kechnie.)

The arrangement, number, and names of the teeth in the permanent set will be found below :—

				Middle line of mouth.					
Upper jaw	3	2	1	2 ↓ 2	1	2	3	=16	=32
Name of teeth	True molars	Bicuspids	Canine	Incisors	Canine	Bicuspids	True molars		
Lower jaw	3	2	1	2 ↑ 2	1	2	3	=16	

In a fully-developed permanent set the incisors and canine are generally used for biting off the food, and the bicuspids and molars for crushing or masticating the food. The rule is for one of the upper teeth to work on a portion of two of the lower ones, and this

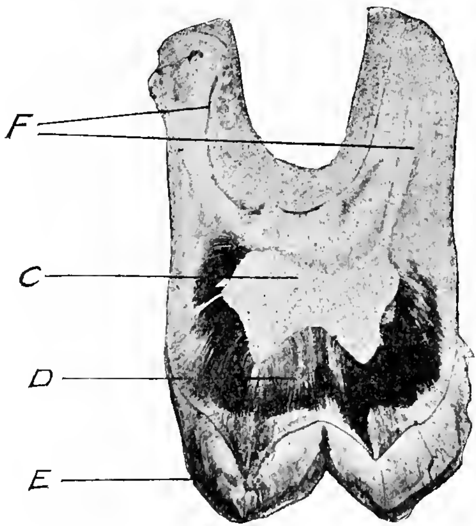

FIG. 59.—Longitudinal section of human molar tooth. *F.* fangs; *C.* pulp cavity; *D.* dentine; *E.* enamel of crown. (Photomicrograph by Flatters, Milborne & M'Kechnie.)

prevents any tooth from becoming useless through the loss of an opposing tooth.

THE STRUCTURE OF TEETH.—Each tooth is made up of a crown which projects well above the gum, a fang (or fangs) which is embedded in a tooth-socket in the gum, and a construction between the above which forms the neck (Fig. 59). In the tooth there is a cavity which contains nerves and blood-

vessels for its nourishment—the pulp cavity. The crown is made up of enamel, which is the hardest substance in the body, and the bulk of the tooth consists of dentine, while the fang is covered with cement. Each tooth is fixed in its socket by the fibrous periosteum, which lines the socket gripping its fangs firmly, and this is aided by the action of the cement which unites them together.

THE PHARYNX.—The pharynx is a funnel-shaped cavity at the back of the mouth (Fig. 76). Its walls are composed of striated muscles, and it is lined with mucous membrane, which is a continuation of that in the mouth. Numerous mucous glands pour their secretions into the pharynx. The upper portion of the pharynx is lined with ciliated mucous membrane. The mouth, posterior nares, glottis, and œsophagus open into the pharynx. At the sides of the pharynx there are a pair of tonsils, and these guard the opening into the windpipe and œsophagus. Many of the cells of which the tonsils are made up can destroy bacteria, and thus prevent them from passing into the lungs and stomach.

Experiment 27.—Stand in front of a looking-glass and examine your own mouth. Note (1) The front is made up of lips and teeth; (2) the sides consist of cheeks and teeth; (3) the top is formed by the hard palate in front, and soft palate behind; (4) the floor is formed of tongue and submaxillary bone; (5) the mouth cavity is lined by red mucous membrane.

Experiment 28.—(1) Make a sketch of a tooth, and mark on the drawing (i) the crown; (ii) the neck; (iii) the fang or fangs.

(2) If a hollow tooth can be obtained from the dentist's, examine the pulp cavity, which contains in the living tooth blood-vessels and nerves.

(3) If possible, examine a prepared vertical section of a tooth, and sketch. Mark on your sketch, and note (i) the enamel which covers the crown; (ii) the cement which covers the fangs; (iii) the dentine, which forms the bulk of the tooth; (iv) the contents of the pulp cavity (Fig. 58).

(4) Obtain a number of teeth from a dentist, and arrange them into four groups, as incisors, canine, bicuspids, and true molars. (i) An incisor tooth will be recognised by its chisel-edge, single fang, and bluish colour. (ii) A canine tooth possesses a single fang, a pointed apex or chisel edge, and it is generally bluish in colour. (iii) A bicuspid tooth is much larger than either of the above. It possesses two fangs, and generally a well-developed crown of two cusps. (iv) A permanent molar tooth may possess three fangs, and the crown is well-developed for grinding the food.

Experiment 29.—(1) Obtain from a butcher a fresh stomach of a pig, and examine it. Note (i) that it is bagpipe-shaped; (ii) find the opening of the œsophagus into the stomach, and the opening at the pyloric end; (iii) that the stomach can be stretched. This shows that it can be distended when food enters.

(2) Now cut the stomach open, and make out (*a*) the four coats (p. 133), and (*b*) the sphincter muscles at the opening of the œsophagus and at the pyloric end.

(3) Cut a piece out of the stomach, and with a hand-lens examine the mucous coat. There will be seen in it a series of many-sided openings which give the appearance of honeycomb, and in the bottom of which are the mouths of the gastric glands.

(4) Tease out a small piece of the mucous coat with needles in salt solution, and with a microscope look for the gastric glands.

Experiment 30.—(1) Obtain a few feet of the small intestine of the ox and cut it open. With a hand-lens look (i) for the four coats. (ii) Now find the numerous villi, which are finger-like projections of the mucous coat. (iii) Tease up a small piece of the mucous coat in salt solution, and with a low power look for the villi.

(2) In a similar manner obtain a piece of the large intestine of ox or pig. Note (i) the puckered up or sacculated appearance, which is due to the longitudinal layer of muscle being shorter than the rest of the tube. (ii) Make out the four coats. (iii) Open the tube, and look for the glands of Lieberkuhn.

THE ŒSOPHAGUS.—The œsophagus is the narrowest portion of the alimentary canal, and it commences in the pharynx, and opens into the stomach near the cardiac end. In the neck it runs between the windpipe and the backbone, and in the thorax passes behind the heart and pierces the diaphragm. Its walls are made up of four coats, which are given below:—

(1) The fibrous coat, which is made up of loose fibrous connective tissue, and is not well developed.

(2) The muscular coat, which consists of (*a*) an outer longitudinal layer, and (*b*) an inner circular layer of muscle. The upper 4 or 5 inches of this coat consist of striated muscle, and the lower portion of plain or non-striated muscle.

(3) The submucous coat, which consists of loose areolar tissue, and the lower portion contains numerous mucous glands, the ducts of which open on the surface of the mucous coat.

A thin layer of unstriped muscle comes between the submucous and mucous coats.

(4) The mucous coat, which lines the interior of the œsophagus.

The œsophagus has an average length of from 8 to 10 inches, and its opening into the stomach is protected by a ring or sphincter muscle. It is closed when food is not passing down, but as soon as a bolus of food touches the upper portion the striated muscle grips it, and by the muscular contraction of this coat the food is passed into the stomach.

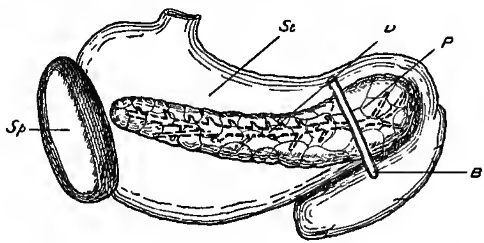

FIG. 60.—Diagram to illustrate the position of the stomach, spleen, and pancreas. *St.* stomach as seen from the back; *P.* pancreas; *D.* duct of pancreas; *Sp.* spleen; *B.* common pancreatic bile duct entering duodenum.

THE STOMACH.—The stomach is a dilated or bag-shaped portion of the alimentary canal, and it comes between the lower end of the œsophagus and commencement of duodenum. It is placed just beneath the diaphragm, with the large or cardiac end on the left side, and the small or pyloric end on the right side. The liver overlies the upper or smaller curvature of the stomach, the spleen touches the cardiac end, and the pancreas occupies the loop between the duodenum and lower edge or greater curvature of stomach (Fig. 60). The walls of the stomach consist of four coats. These are:—

(1) The outer coat consists of the visceral layer of

the peritoneum, or lining membrane of abdomen, and which is reflected round most of the organs found in the abdomen.

(2) The muscular coat consists of (*a*) an outer layer of

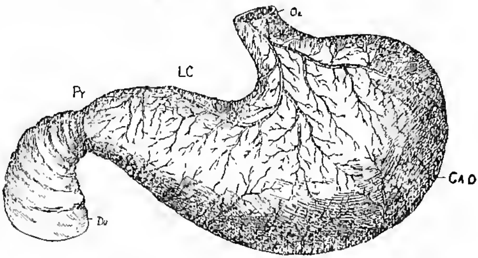

FIG. 61.—The human stomach. *Oe.* œsophagus; *Py.* pyloric end; *Ca.D.* cardiac end; *L.C.* lesser curvature; *Du.* duodenum.

longitudinal non-striated muscle; (*b*) a circular layer of muscle, and an inner oblique layer. The middle layer is very thick at the pyloric end of stomach, where it

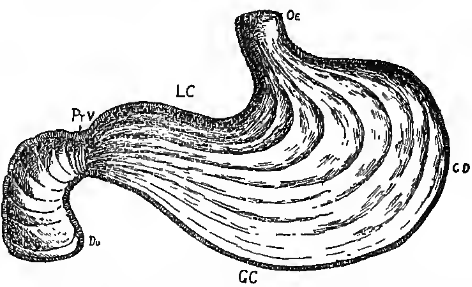

FIG. 62.—Vertical section of human stomach. *Oe.* œsophagus; *C.D.* cardiac end of stomach; *Py.V.* pyloric valve; *L.C.* lesser curvature; *G.C.* greater curvature; *Du.* duodenum.

forms most of the sphincter muscle, which guards the pyloric opening.

(3) The submucous coat consists of loose connective tissue, and it contains blood-vessels, nerves, and lymphatics.

(4) The mucous coat consists of fine connective tissue, and this is covered with a layer of columnar epithelium. The mucous coat in the empty stomach is slightly folded, and in that of the frog this condition is greatly exaggerated (Fig. 63). The mucous coat is fairly thick, and contains a number of gastric glands. The structure of these will be considered in Chapter XIV.

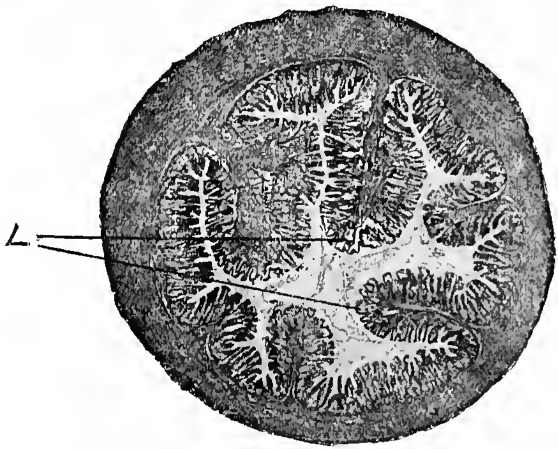

FIG. 63.—Transverse section of stomach of frog, showing longitudinal folds with gastric glands, *L*. (Photomicrograph by Flatters, Milborne & M'Kechnie.)

THE SMALL INTESTINE.—The small intestine comes between the pyloric end of the stomach and the cæcum. It is a convoluted tube, about 20 feet in length, and is held in place by the mesentery. It is divided into three parts; the first 10 inches is known as the duodenum, the next 8 feet form the jejunum, and the remaining portion, which is about 11 feet in length, forms the **ileum.** The common bile duct opens into the duodenum, and through which the pancreatic juice and bile enters (Fig. 60). The walls

of the small intestine, like the rest of the alimentary canal, consist of four coats. These are :—

(1) The outer serous coat, which is similar in nature to that of the stomach.

(2) The muscular coat consists of an outer longitudinal layer and an inner circular layer, between which there is a layer of nerve fibres.

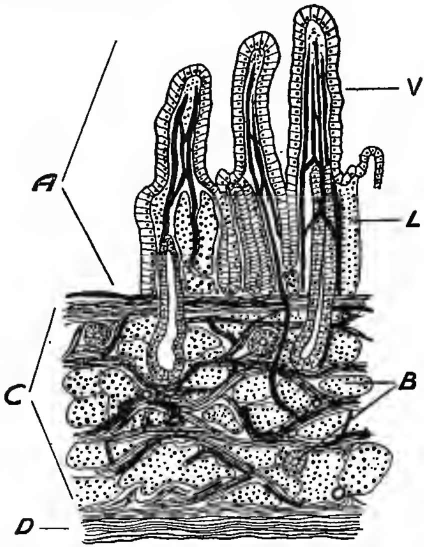

FIG. 64.—Transverse section of small intestine. *A.* mucous coat; *V.* villus; *L.* crypts of Lieberkuhn; *C.* submucous coat; *B.* Brunner's glands; *D.* circular layers of muscular coat. (The serous coat is omitted.)

(3) The submucous coat consists of loose connective tissue. This contains lymphatics, Brunner's glands, and blood-vessels.

(4) The mucous coat consists of fine connective tissue, and it is covered with a layer of columnar epithelium. It contains numerous villi, glands or crypts of Lieberkuhn, and Peyer's patches. The

mucous coat is thrown into transverse folds, which are known as **valvules conniventes.** These commence in the duodenum, increase in size in the jejunum, but their size decreases, and they end about the middle of the ileum. The area of the mucous coat is increased by the valvules conniventes, and they are covered with villi. The villi are fingerlike projections of the mucous coat, and their structure will be considered in Chapter

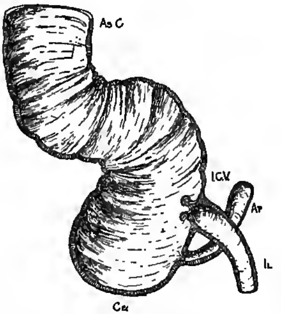

FIG. 65.—The left side of cæcum removed to show entrance of ileum and vermiform appendix. *Ca.* cæcum; *Il.* ileum; *I.C.V.* ileo-cæcal valve; *Ap.* vermiform appendix; *As.C.* ascending colon.

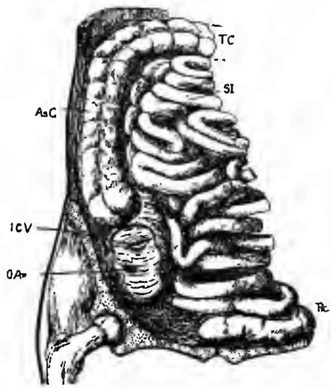

FIG. 66.—Diagram to show the position of the ileo-cæcal valve. The front of the cæcum has been removed. *I.C.V.* ileo-cæcal valve; *O.Ap.* opening of vermiform appendix; *As.C.* ascending colon; *T.C.* transverse colon; *R.C.* rectum; *S.I.* portion of fold of small intestine.

XV. Brunner's glands are only found in the duodenum, and they are depressions in the submucous membrane, the cells of which probably help to secrete intestinal juice. The glands of Lieberkuhn are found in both the large and small intestines, and they are tubular depressions in the mucous membrane.

THE LARGE INTESTINE.—The large intestine,

which is about 6 feet in length, comes between the end of the ileum and the opening of the rectum in the anus. It is divided into cæcum, colon, and rectum. The cæcum is the first portion, and the small intestine opens into it by the ileo-cæcal valve. At the blind end of the cæcum comes the vermiform appendix (Fig. 65). The ileo-cæcal valve is formed by folds of membrane and the end of the ileum which protrudes into the cæcum, and the food pressing on these closes the opening, thus preventing the backward movement of the contents of large intestine. The cæcum is found on the right side of the abdomen, and it opens into the ascending colon, which passes up the right side. The transverse colon crosses the abdomen just beneath the stomach. The descending colon passes down the left side, and ends in the rectum, which opens by the anus. The walls of the large intestine consist of four coats. These are:—

(1) The outer serous coat consists of a layer of peritoneum.

(2) The muscular coat, the outer longitudinal layer in the cæcum and colon, is arranged in three bands, which are shorter than the other coats, and because of this it is puckered up to form a sacculated tube (Fig. 55). The inner circular layer of muscle is like that of the small intestine, and is very thick at the end of rectum, where it forms a sphincter muscle. The rectum is not sacculated, but smooth.

(3) The submucous coat of loose connective tissue, which contains lymphatics and blood-vessels.

(4) The mucous coat consists of fine connective tissue, which is covered with a layer of columnar epithelium. The tubular glands of Lieberkuhn open on its surface.

QUESTIONS FOR REVISION

1. Give an account of the arrangement of the alimentary canal.

2. Describe the structure of the mouth, dwelling especially on the mucous membrane, lower jaw, and tongue.

3. Enumerate the position, number, and kinds of teeth found in the milk set.

4. Describe the parts present in a tooth. Give a sketch.

5. Enumerate the number, position, and arrangement of the teeth in the permanent set.

6. In the case of the œsophagus, state its position, shape, general structure, and uses.

7. Carefully describe the exact position, shape, general structure, and use of the stomach.

8. Where does the small intestine commence and end, and how does it lie between its two ends?

9. Give a general account of the structure of the small intestine.

10. Enumerate the various parts of the large intestine, giving the exact position of the parts you mention.

11. What is the ileo-cæcal valve, and where is it found? Of what service is the ileo-cæcal valve?

12. Describe the general structure of the large intestine.

CHAPTER XII

THE LIVER

THE liver is a reddish-brown organ which overlies the pyloric end of the stomach on the right side, and it is connected to the diaphragm by five strong ligaments. A fully-developed liver weighs 50 ounces, and it consists of five lobes, two large and three small ones. A layer of the peritoneum nearly covers the liver, and beneath this there is a layer of fine connective tissue, which forms Glisson's capsule; this enters the liver along with the blood-vessels and hepatic duct, dividing the lobes into lobules. It is very irregular in shape, but is nearly oblong, and its thickness varies from about 1 inch at the extreme edge to several inches in the thickest portion.

Experiment 31.—(1) Obtain a perfectly fresh sheep's liver, with the gall-bladder attached, and make out (i) the reddish-brown colour. Note the convex upper surface and concave lower surface, in a cleft of which the gall-bladder will be seen. Find the ligaments by which it was fixed to the diaphragm; these will be found on the upper convex surface. Measure the thickness of the liver, and note that it thins out towards the edges. (ii) Now with a pair of forceps pick up the very thin membrane which surrounds the liver; this is Glisson's capsule. It passes into the substance of the liver along the blood-vessels and divides the lobes. Find the two large lobes, a right and a

left (Fig. 67), and the three smaller ones, which are between the above. (iii) Turn the liver with its lower surface upwards, and note the shape of the gall-bladder and the cleft in which it is fixed. Find the **cystic duct**, which enters the small end of the gall-bladder, and trace it from the bladder to where it joins the **hepatic duct**, which conducts the bile from the liver to the cystic duct. Now follow the hepatic duct to where

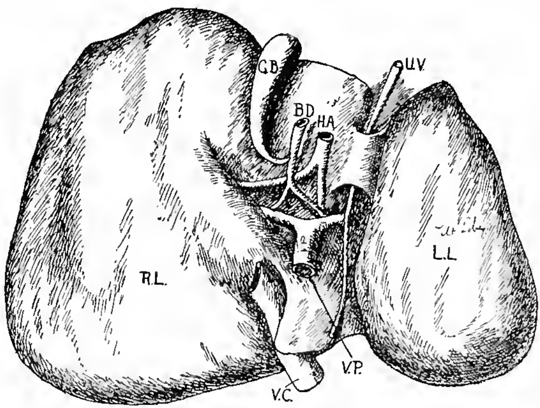

FIG. 67.—Diagram showing under-surface of liver. *R.L.* right lobe; *L.L.* left lobe; *V.P.* portal vein; *H.A.* hepatic artery; *B.D.* bile duct; *G.B.* gall-bladder; *V.C.* inferior vena cava; *U.V.* umbilical vein.

it enters the liver. Now carefully remove the gall-bladder so as not to spill the bile, and place in a glass jar. (iv) Try and find the blood-vessels. The thick-walled **hepatic artery** will be found near where the hepatic duct enters the liver. It can be distinguished by its open mouth and thick walls. (v) Near the hepatic artery a thin-walled vessel will be seen with its mouth closed, which is slightly larger than the hepatic artery; this is the **hepatic vein**. Look for the factors of the hepatic vein, which leave the

liver and join to form one large vein, the hepatic vein, which enters the inferior vena cava. (vi) Find the cut end of the **portal vein** which brings venous blood to the liver. It is a fairly thick-walled vessel which enters the liver along with the hepatic artery.

(2) Now carefully dissect the liver so as to make out the following structures: (i) Trace the portal vein into the substance of the liver. Pass a seeker or bristle through the opening of the portal vein and cut along the instrument. This will lay open the portal vein, and if the same is done to its branches they can be followed into the substance of the liver. Note how its branches pass into all parts of the liver. (ii) In a similar manner follow both the hepatic artery and hepatic vein. (iii) Now follow the hepatic duct and its factors into the liver, noting that its factors lie near to the branches of the portal vein. (iv) Cut through a lobe, and find the small lobules of which it is composed. Each lobule is about the size of the head of an ordinary pin. (v) Empty the gall-bladder, and look for the outer serous coat, the inner mucous coat, and the middle muscular layer.

(3) Scrape the freshly-cut surface of the liver, and mount the scrapings in a drop of salt solution. Look for the hepatic cells. Each cell is about the $\frac{1}{1000}$ of an inch in diameter and polygonal in shape. It contains numerous granules, and a nucleus which is embedded in its surface. Mount on a slide some hepatic cells with a drop of iodine solution, and with the microscope note that the granules are stained a port-wine colour.

(4) If possible examine a prepared section of a mammalian liver under a low power. Observe (i) the different lobules; (ii) the **interlobular veins** between the lobules, which open into the capillaries; (iii) the **hepatic cells**, which fill in the spaces between the

capillaries of a lobule; (iv) the single veinlet in the centre of the lobule, which receives blood from the capillaries and is known as the **intralobular vein.**

(5) Place a little of the bile in a test-tube and note its greenish colour. (i) Test its reaction with damp litmus papers, noting that it is alkaline. (ii) Now add a little olive oil to the bile in the test-tube; shake and keep warm; an **emulsion** is formed. Let it stand for some time; the emulsion is not permanent. (iii) Fold two filter papers, insert them into funnels; moisten one with bile and the other with water. Pour a little oil into each. Drops of oil pass slowly through the one moistened with bile.

THE MINUTE STRUCTURE OF THE LIVER.—Each lobe of the liver is divided into a large number of irregular-shaped **lobules**; the size of each is about $\frac{1}{20}$ of an inch in diameter, and it is composed of:—

(1) The **interlobular veins**, which come between the lobules. These are formed by the division of the branches of the portal vein, and they convey venous blood to the capillaries.

(2) The **capillaries**, which connect the interlobular veins to the single **intralobular vein** in the centre of the lobule.

(3) The **hepatic cells**, which come between the capillaries, and are so arranged that one side touches a capillary. Each hepatic cell is about the $\frac{1}{1000}$ of an inch in width, and it contains granules of glycogen, and either a single nucleus or more than one may be present.

(4) Between the hepatic cells small openings may be seen; these are the **bile capillaries**, which carry away from them the bile which they form, and they empty their contents into the factors of the hepatic duct.

THE BLOOD SUPPLY OF LIVER

The liver receives a double blood supply by the hepatic artery and portal vein.

(1) The **hepatic artery**, which is a branch of the aorta, brings arterial blood to the liver, and, as we have seen, it branches within the substance of the liver to form small arteries. These supply blood for the nourishment of the walls of the portal vein and hepatic duct, Glisson's capsule, and other parts of the liver, the blood finding its way into the capillaries of the lobules.

(2) The **portal vein** brings blood from the stomach, intestine, pancreas, and spleen. The veins (factors) which collect the blood from the above organs unite to form the portal vein, and it runs in the mesentery to the under-side of the liver (p. 142). It enters the liver, and its branches enter the portal canals, where they divide into smaller veinlets, the **interlobular veins.** These pass between the lobules and supply blood to the **capillaries.** The blood is collected from the capillaries by **intralobular veins,** which empty into **sublobular veins,** which come beneath the lobules.

(3) The factors of the **hepatic vein** receive blood from the sublobular veins, and discharge into one main trunk, the **hepatic vein,** which opens into the **inferior vena cava.**

THE PORTAL CIRCULATION.—In a former chapter we studied the pulmonary and systemic circulations, and now the circulation through the liver remains to be considered. The movement of blood through the liver is known as the portal circulation. This is shown on the following page.

Arterial Blood.

Aorta

↓

Hepatic artery, which branches, and these supply blood to the

Capillaries for the nourishment of liver (p. 144), and this enters the

→ Interlobular veins

Venous Blood.

The factors or veins which collect the blood from the stomach, intestine, pancreas and spleen discharge into the

↓

Portal vein which enters the liver.

↓

Branches of portal vein again branch to form

↓

Interlobular veins, which run between the lobules; these supply blood to the

↓

Capillaries of lobules, which empty into the

↓

Intralobular veins; these discharge their blood into the

↓

Sublobular veins, which discharge blood into a number of

↓

factors, which unite to form one trunk, the

↓

Hepatic vein, which empties into the

↓

Inferior vena cava.

From the above it will be seen that the arterial blood, which is supplied to the stomach, intestines, pancreas, and spleen, and which becomes venous during its passage through the capillaries of these organs, goes through a second set of capillaries in the lobules of the liver. The portal vein is an example of a vein dividing up to form branches, and these to form a second set of capillaries. The blood in moving through the capillaries of the liver must move slower than through an ordinary capillary system, and the hepatic

cells take substances from the blood during its circulation through the capillaries. From these they form bile and glycogen. The venous blood brought to the liver by the portal vein will vary in quality; it will contain more proteins and sugar some time after digestion has gone on than before digestion.

THE FUNCTIONS OF THE LIVER

The blood which passes through the capillaries of the lobules contains certain substances from which the hepatic cells form bile, glycogen, urea, and uric acid. The formation of the substances just enumerated by the hepatic cells constitute the functions of the liver.

(1) THE FORMATION OF BILE.—From the blood, which reaches the liver along the portal vein, the hepatic cells secrete bile. Bile is a golden yellow fluid in man, or greenish in the ox and sheep. It is slightly alkaline and very bitter. The composition and functions of the bile we shall consider in connection with the chapter on digestion.

HOW THE BILE REACHES THE DUODENUM.—The bile passes from the hepatic cells into the bile capillaries, and from these into the factors of the hepatic duct. The hepatic duct discharges the bile into the common bile duct if food is being digested in the duodenum, or through the cystic duct into the gall-bladder to be stored up until needed. This is shown on the following page.

Hepatic cells.
↓
Bile capillaries (p. 143).
↓
Factors of hepatic duct.
↓
Hepatic duct.

↓ Cystic duct
↓ Gall-bladder
↓ When food enters the duodenum it passes from the gall-bladder along the cystic duct to the → Common bile duct to duodenum.

(2) THE FORMATION OF GLYCOGEN.—From the proteins and sugar in the blood of the portal vein, the hepatic cells form glycogen or liver starch. Glycogen has the same composition as starch, but its reaction with iodine solution differs, for starch turns a deep blue colour and glycogen a port-wine colour. The glycogen appears in the hepatic cells as granules, and it forms a reserve material for future use. The amount of proteins and sugar in the blood brought to the liver varies, and some of the sugar and proteins are changed into glycogen, in which form it can be kept for use at some future time. The glycogen can be changed into sugar by the action of an enzyme, which is also formed in the liver.

QUESTIONS FOR REVISION

1. What is the liver? Where is it found? What is its shape and general appearance?
2. Describe the structure of the liver.
3. Give an account of the structure of a lobule of the liver.
4. Where does the portal vein commence, and how does it enter the liver? Does the blood in the portal vein vary in composition? If so, when?

5. Trace out the course of the portal circulation.
6. Enumerate the functions of the liver.
7. Explain how the blood reaches (*a*) the gall-bladder ; (*b*) the duodenum.
8. What is glycogen? Where is glycogen found, and what is its use?

CHAPTER XIII

FOOD

THE excretory organs, the lungs, skin, and kidneys, are always removing from the blood waste substances, such as carbon dioxide, water, urea, uric acid, and mineral salts. These contain the elements carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, calcium, &c. For the weight of the normal adult body to remain constant, the food which enters the alimentary canal must contain an equal quantity of the elements removed by the excretory organs. It is self-evident that if food be abstained from for any length of time, the weight of the body decreases, and the strength declines, until death may take place from starvation. The experience of every-day life leads us to believe that the food must contain all the substances necessary for the upkeep or repair of the tissues and to produce energy. We will now proceed to ascertain what substances are contained in food.

Experiment 32.—(1) Dilute a little new milk with an equal quantity of water, and place a drop on a glass slide; cover and examine with the high power. Note the large number of bright-looking or highly refractive fat globules, which vary in size and float in a liquid plasma. Sketch.

(2) Drop a little cream into a quantity of water, and note that the cream floats and the water appears greasy.

(3) Place a little of the skim milk, from which the

cream has been removed, in a test-tube. Add a few drops of essence of rennet, and warm. The milk breaks, or is separated into a solid portion, the curd, and a liquid portion, the whey.

(4) Remove the curd from the whey, and dry it in a test-tube until it burns. Note (i) the length of time it takes to remove all the water; (ii) the change from dirty white to brown, which the curd undergoes as heat is applied, and the pungent smell of burnt hoof or hair; (iii) the black mass of charcoal which remains.

(5) Taste some of the whey; it is sweet; the sweet taste must be due to sugar.

(6) Measure 5 c.c. of whey, and dry in a porcelain dish. Now burn off the carbon in the sugar; a residue of ash will remain, which represents the mineral matters in the milk.

The above experiments demonstrate that milk contains butter fat, curd which smells like burnt hoof or hair when burnt, sugar which is sweet, and mineral salts.

Experiment 33.—(1) Place a little of the white of a hard-boiled egg or a little fibrin in the test-tube, and dry until it burns to charcoal. Note the change in colour, and the smell, which is similar to burnt curd. Hold over the mouth of the test-tube a piece of damp red litmus paper; it turns blue. In Chapter VII. the fibrin was mentioned as a protein, and the chemist has also discovered that the white of egg contains albumin, which is also a protein. In addition, the curd of milk and white of egg when burnt possesses the characteristic smell of substances which contain nitrogen. From this we must conclude that the curd of milk is of the nature of a protein.

(2) Obtain an egg, and open both ends with a pin,

and gently blow the white of the egg into a flask. Mix with twice its bulk of water, and shake. Now boil a little of the white of egg solution in a test-tube; the white of egg coagulates. This is also a common character of proteins, for they are coagulated by heat. This confirms the experiments performed above.

(3) Place a little cream in a test-tube, and treat with a drop of a 1 per cent. solution of osmic acid; the cream turns black. Repeat, but use (i) a little butter; (ii) a piece of beef fat. The cream, butter, and beef fat all agree in turning black with osmic acid. Why? Because this is the common colour test for fats, and all substances of this nature give the same reaction.

(4) Burn a little of the butter in a test-tube, and note how it changes. It melts, and bubbles of steam rise from the bottom of the tube. At last it changes to a brown colour, and smells like rancid bacon or butter. Damp a piece of blue litmus paper and hold in mouth of tube; it turns red. Repeat the experiment with cream. Results much the same. During the burning of the fat an acid substance is formed, and this gives the characteristic smell and reaction to litmus.

(5) Boil a little whey for some time. Now add four times its volume of Fehling's solution. Boil. Note the yellow or yellowish-red precipitate of copper oxide which is formed. This is a test for a reducing sugar, or one which can reduce copper compounds. (Milk sugar, as the sugar found in milk is called, can be inverted by heat.) Repeat this experiment, but use a little malt or grape sugar.

(6) Place a little cane sugar in a test-tube, and apply heat. Note it smells, turns brown, then burns, dense fumes or smoke of a light-bluish colour leaving the mouth of the tube, and at last a mass of charcoal

remains. The smell of burnt sugar is much like that of burnt wood.

(7) The milk also contains, in addition to the substances discovered above, water and salts.

(8) Now dry some milk in a test-tube until it burns. Note (i) that it takes a long time to dry; (ii) that the bubbles of steam may blow out the whole of the milk from the tube; (iii) that the smell combines the smell of a protein, fat, and sugar.

CONCLUSIONS.—The above experiments demonstrate that milk contains a protein, a fat, a sugar, water, and mineral salts.

MILK.—Milk is produced by female mammals, and their offspring live on it during the early period of growth. From this we may assume that milk contains everything necessary for the growth of the body, and in about the right proportion. In addition it is easy to digest and assimilate. Milk varies in composition, for this depends upon the varying needs of the offspring at different periods of life, and upon the rate of growth. Those mammals whose offspring grows the quickest produce milk richer in proteins than those whose young make a slower rate of growth. The milk of the same mammal also varies in composition during the suckling period, and this largely accounts for the variation in cow's milk. All experience seems to show that there is no better food for young children than milk, and no other food should be given during the first year of life. From the consideration of numerous analyses the following can be taken as an average composition of human and cow's milk:—

	Cow's Milk. Parts per 100.	Human Milk. Parts per 100.
Water	87·5	88·6
Proteins . . .	4·2	2·7
Fats	3·8	3·5
Milk sugar . . .	3·8	5·0
Salts	0·7	0·2
	100·0	100·0

THE FOOD SUBSTANCES.—From the consideration of the composition of milk, which is a perfect food, we naturally come to the conclusion that all foods should contain similar substances, and that these are much simpler in composition than the foods in which they may be found. These receive the name of food substances or stuffs, and they can be classed under a number of heads. We will now consider their characters and how they are classified.

Experiment 34.—(1) Make some white of egg solution (Experiment 33), and place a little in a test-tube. Add a few drops of strong nitric acid and boil. A white precipitate is produced, which has a tendency to turn yellow and dissolve. Cool under a stream of running water, and add a solution of ammonia; the precipitate turns an orange colour. The colour test you have just used is a well-known one for proteins, and it receives the name of **xanthoproteic reaction.**

(2) Burn a little piece of lean meat in a test-tube, and note the change in colour. It gives the characteristic smell of a protein, which is similar to burnt white of egg and curd.

Experiment 35.—(1) Repeat Experiment 33, but use some beef dripping. The osmic acid stains it black. This is the well-known colour test for fats.

(2) Dry a little of the dripping in a test-tube until it burns. Note the change in colour and characteristic smell, like rancid bacon or butter.

(3) Place a little of the dripping in a test-tube, add water, and shake; they will not mix.

(4) In a similar manner try again, but use a solution of washing soda; an emulsion is formed. This is due to the alkaline solution breaking up the globules of fat so that they will mix with water.

Experiment 36.—(1) Obtain a piece of prepared starch, such as that used for stiffening linen. Allow a few drops of iodine solution to touch the starch; it turns a deep bluish-black colour.

(2) Apply a similar test to some flour; a blue colour is given, but the shade differs from the above.

(3) Place some iodine solution on a slice of bread; a distinct blue colour is obtained.

(4) Now try a slice of potato; it also gives the same colour reaction.

This is the common colour test for starch.

(5) Place a little cotton wool in a test-tube or porcelain dish, add a few drops of iodine solution; it turns yellow. Wash and add a few drops of sulphuric acid; it turns blue.

This is the common colour test for cellulose.

(6) Dissolve a little malt or grape sugar in some water, or squeeze the juice of a grape into a test-tube. Add four times its volume of Fehling's solution, and boil. A yellowish-red precipitate is obtained.

This is the colour test for reducing sugars.

(7) Try a similar experiment, but use cane sugar. There is no result. Boil a little of the cane sugar with a few drops of sulphuric acid, and again apply Fehling's solution; the reaction of reducing sugar is obtained.

Why? The sulphuric acid has decomposed the cane sugar into two reducing or **invert** sugars.

(8) Now burn in succession a little starch, cellulose, and cane sugar. Note the results, and especially that in each case charcoal is produced.

Experiment 37.—(1) Dissolve a piece of gelatin in some hot water, and allow to cool in a test-tube; it sets like jelly.

(2) Treat some white of egg solution in a similar manner. No change takes place. This shows that gelatin differs from egg protein.

(3) Add to a little of the liquid gelatin a few drops of Millon's solution. Boil. The solution turns a **faint red colour.**

(4) Apply the same test to a little white of egg solution. **A dark red brick colour is obtained.**

CONCLUSIONS.—The above experiments demonstrate that gelatin differs from an ordinary protein (1) in the temperature at which it solidifies; (2) in colour reaction.

THE CLASSIFICATION OF THE FOOD SUBSTANCES.—The experiments which we have performed clearly indicate that there is *no nitrogen* in fat, starch, cellulose, nor sugar. They also show that food contains certain elementary materials, which receive the name of food substances. The food substances can be divided into two main groups, as:—

Nitrogenous	Proteins Albuminoids	Contain nitrogen.
Non-nitrogenous	Fats Carbohydrates Minerals	Contain *no* nitrogen.

The classification of the food substances, the elements they contain, the fuel value, and percentage of digestibility will be found in the following table:—

Food Substance.	Elements in Food Substance.	Common Examples.	Fuel Value in Calories per Gram.	Digestibility in a mixed Diet.
Proteins.	Carbon. Hydrogen. Oxygen. Nitrogen. Sulphur.	Glutin. Legumin. Casein. Fibrin. Myosin. Albumin.	4 calories per gram.	92 per cent.
Albuminoids.	Carbon. Hydrogen. Oxygen. Nitrogen. (In some sulphur is also present.)	Gelatin.	4 calories per gram.	92 per cent.
Fats.	Carbon. Hydrogen. Oxygen.		8·9 calories per gram.	95 per cent.
Carbohydrates.	Carbon. Hydrogen. Oxygen.	Starch. Grape sugar. Malt ,, Cane ,, Milk ,, Cellulose. Inulin.	4 calories per gram.	97 per cent.
Minerals.	Sodium. Chlorine. Potassium. Phosphorus. Calcium. Magnesium. Iron, &c.	Common salt. Phosphates. Potash. Compound of iron.		

These divisions of the food substances we will now proceed to study more in detail.

1. THE PROTEINS.—The chemical elements which the proteins contain will be found in the table on previous page, and their percentage composition is:—

Carbon	from	50·6	to	54·5
Hydrogen	„	6·5	„	7·3
Oxygen	„	21·5	„	23·5
Nitrogen	„	15·0	„	17·6
Sulphur	„	0·3	„	2·2

The proteins are the only food substances which can repair the waste of the tissues, and their oxidation also produces energy. They aid in the absorption of oxygen, and regulate the changes which the tissues undergo. If the weight of the body is to remain constant, there must be just as much nitrogen in the proteins as leaves the body in the waste materials.

2. THE ALBUMINOIDS.—The albuminoids contain the same chemical elements as the proteins, but they are linked together in a different way, and some of the members of the group are without sulphur. The chief albuminoid used as food is gelatin, and it contains:—

Carbon	50·76
Hydrogen	7·15
Oxygen	23·21
Nitrogen	18·32

Gelatin thus differs from the proteins in containing no sulphur and a little more nitrogen. It is produced when connective tissue or bones are boiled in water. On oxidation the albuminoids produce energy, but they cannot repair the tissues, and only replace the circulating proteins, or those which circulate in the fluids of the body.

3. THE FATS.—The fats contain carbon, hydrogen, and oxygen; the hydrogen and oxygen not being present in the proportion to form water. The common fats are palmitin, olein, stearin, and butyrin. They consist of fatty acids and glycerine. The fats on oxidation produce energy, and, as will be seen from the table on p. 156, 1 gram will produce more energy than 2 grams of starch or sugar. Health cannot be maintained without a due proportion of fats in a diet.

4. THE CARBOHYDRATES.—The carbohydrates contain the same elements as fats, but the hydrogen and oxygen are present in the same proportion as they exist in water. Examples of the carbohydrates will be found in the table on p. 156. On oxidation they produce energy, and they may form fats in the body. In the production of energy in the body the carbohydrates are first called upon, and if the amount produced is not sufficient, the fats are oxidised, but the proteins are only called upon when the above food substances cannot produce the quantity required.

5. THE MINERALS.—All kinds of food contain minerals, and they are just as necessary in a diet as the other classes of the food substances. They find materials to replace those removed from the body by the excretory organs. The chlorine of common salt is used for the formation of hydrochloric acid, and the sodium for the production of bicarbonate of soda. Carbonate and phosphate of lime are necessary for the building up of the bones and for their repair. Phosphorus is an essential ingredient of the nuclei found in cells, and is necessary for the nutrition of nervous tissues. Potash and magnesia seem to be necessary for

healthy growth, and iron is an essential constituent of hæmoglobin.

THE HEAT VALUE OF THE FOOD SUBSTANCES.—If carbohydrates are burnt, they produce heat, and the oxygen used in combustion unites with the carbon present and forms carbon dioxide. When fats undergo combustion the oxidation of the carbon and hydrogen produces carbon dioxide and water. In a similar manner the proteins form carbon dioxide, water, and ammonia.

To measure the amount of heat produced by the food substances when burnt a unit of heat is taken as a standard measurement. This is known as the calorie, and it is the amount of heat necessary to increase the temperature of a litre of water 1 degree Centigrade. To ascertain the number of units of heat which the food substances can produce, they are burnt in a calorimeter, and in this way their heat value can be accurately determined.

From numerous experiments with the above instrument it has been discovered that when fully oxidised in a calorimeter:—

One gram of protein produces	5·65 calories.
One gram of fat produces	9·40 „
One gram of carbohydrates produces . .	4·10 „

THE DIGESTIBILITY OF THE FOOD SUBSTANCES.—Numerous experiments have been performed to determine the digestibility of the food substances as they exist in a mixed diet. If 100 parts of a food substance enter the alimentary canal, and 97 are digested, this latter figure represents its digestibility. From the values obtained, the figures given in the table on p. 156 may be said to represent this for

the food substances. The following table illustrates their digestibility:—

Kind of Food.	Coefficients of Digestion.			Fuel Value per Gram in Calories.		
	Proteins.	Fats.	Carbohydrates.	Proteins.	Fats.	Carbohydrates.
Meat	97	95	98	4·25	9·0	3·80
Fish	97	95	98	4·25	9·0	3·80
Egg	97	95	98	4·35	9·0	3·80
Wheat	97	90	98	4·70	8·35	4·10
White bread	85·3	56·4	97·5	3·50	5·30	3·90
Whole wheat bread	80·4	55·8	94·1	3·34	5·24	3·85
Peas and beans	78	90	97	3·20	8·35	4·05
Animal food in a mixed diet	97	95	98	4·25	8·95	3·80
Vegetable food in a mixed diet	85	90	97	3·55	8·35	4·00
The total food in a mixed diet	92	95	97	4·00	8·90	4·00

The above table shows that a greater proportion of the protein substance is digested in animal than in vegetable foods. In animal foods 97 per cent. can be digested, but in vegetable foods only 85 per cent. It shows that white bread is more digestible than whole wheat bread. The carbohydrates vary the least in digestibility, and the fats the most.

AVAILABILITY OF ENERGY.—The energy which can be extracted from a given quantity of a food substance will depend upon the amount which can be oxidised in the body. In the case of the carbohydrates and fats, which are fully oxidised in the body, the availability of energy will equal their coefficients of digestibility. The proteins are not fully oxidised in the body, for the urea in the urine contains a certain amount of energy which is set free when it is decomposed. There is only some 70 per cent. of the total

proteins which can be used for the production of energy in the body. The availabilities of the food substances are shown below:—

Proteins	70 per cent.
Fats	95 ,,
Carbohydrates	97 ,,

THE FUEL VALUE OF THE FOOD SUBSTANCES.—The fuel value equals the amount of heat produced when the food substances are oxidised in the body. If we take the heats of combustion of the food substances and multiply them by the corresponding coefficients of digestibility, the result will be their fuel values. Example: The heat value of the fats is $9{\cdot}40 \times {\cdot}95 = 8{\cdot}9$, its fuel value. The fuel values of the food substances are shown below:—

Food Substance.	Heat Value per Gram.	Coefficients of Digestibility.	Energy in Urea.	Fuel Value in a Mixed Diet.	
				Per Gram.	Per Pound.
Proteins . .	5·65 ×	·92	– 1·2 =	4·0	1840
Fats	9·40 ×	·95	=	8·9	4050
Carbohydrates	4·10 ×	·97	=	4·0	1880

DIETS.—By a diet we mean an organised system or method of feeding. There are several ways of arriving at the quantity of the different food substances which should be present in diets to keep the body in an efficient condition.

(1) The quantity of waste materials leaving the body can be determined, and from this the amount of food necessary to replace the loss can be obtained.

(2) The diets of people in different social conditions can be examined, and the relative quantities of food substances can be determined.

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(3) A person may be placed in the respiration-calorimeter. This is a copper-walled chamber 7 feet long, 4 feet wide, and 6 feet 4 inches high. It is fitted with means for the production of a constant stream of air, and for its analysis. The amount of heat produced by its occupant can be estimated. It contains a folding-bed, chair, table, and a telephone for communicating with the external world. Appliances are supplied for the carrying out of muscular work. The subject of the experiment lives in the chamber for a period of from three to twelve days, a careful record being kept of the amount of food received, and the waste materials given off in the breath and the residue from the alimentary canal. By this means a balance can be struck between the amount of food taken and the heat produced. The amount of food necessary for the different kinds of work performed can also be determined.

AMOUNT OF DRY FOOD SUBSTANCES IN DIETS.—The following table gives the average amount of dry food substances which are present in various diets:—

	Amount in Ounces.			Amount in Grams.			Energy.
	Proteins.	Fats.	Carbohydrates.	Proteins.	Fats.	Carbohydrates.	Calories.
Rest diet . .	2½	1	12	70·87	28·35	340·20	1896
Ordinary diet .	4½	3	14¼	127·57	85·05	403·98	2883
Hard-work diet	6	3½	16	170·10	99·22	453·60	3377

The rest diet will just support life if no external work is performed, and if such a diet was used by a man performing work, he would lose weight. The second diet will keep a man from losing weight while performing ordinary work, and the third will enable a man to perform very hard work. A daily diet should

contain from 3000 to 3500 calories of energy, for these amounts will give reasonable efficiency for the performance of ordinary occupations. In addition to the amount of the dry food substances given in the table, from 50 to 60 ounces of water will be required per day, and from ½ to 1½ ounces of salts.

DIETARY STANDARDS.—It is very instructive and interesting to study the diets of different people with different incomes and performing different kinds of work. The following table, which is taken from one prepared by Professor Atwater, gives the result of his researches:—

QUANTITIES PER MAN PER DAY ACTUALLY EATEN

	Proteins.	Fats.	Carbo-hydrates.	Fuel Value.
Persons with active work—	Grams.	Grams.	Grams.	Calories.
Rowing clubs in New England	155	177	440	3955
Bicycle rider in New York	186	186	651	5005
Swedish mechanics	189	110	714	4590
Persons with ordinary work—				
Farmers' families in Eastern United States	97	130	467	3415
Mechanics' families in United States	103	150	402	3355
Russian peasants	129	33	589	3165
Professional Men—				
Lawyers, teachers, &c., in United States	104	125	423	3220
Japanese professor	123	21	416	2345
Men with little or no exercise—				
Men (American) in respiration calorimeter	112	80	305	2380
Men (German) in respiration apparatus	127	80	302	2430
Persons in destitute circumstances—				
Poor families in New York	93	95	407	2845
Italian mechanics	76	38	396	2225

ARTICLES OF FOOD.—The foods which are obtained from the stores receive the name of articles of food, and these contain one or more foodstuffs or substances. The following table gives the food substances found in some common articles of food.

Articles of Food.	Water.	Proteins.	Fats.	Carbo-hydrates.	Minerals.
Bread	13	12	2	72	1
Oatmeal	16	13	6	63	2
Rice	14	5	1	79	1
Potatoes	75	2	0·2	21·8	1
Turnips	92	1	0·2	6·1	0·7
Cabbages . . .	85	5	0·5	8·3	1·2
Sugar	2·16	...	...	93·3	0·76
Arrowroot . . .	...	...	...	nearly 100	...
Sago . . .	...	...	...	do.	...
Tapioca . . .	...	...	...	do.	...
Beef	74·5	21	2·5	0·7	1·3
Mutton	75·2	20·1	3·0	0·5	1·2
Pork	72·0	20	6·5	0·5	1
Cheese (Cheshire) .	37·6	28	30·0	...	4·4
Butter . . .	15	1·2	83	0·3	0·5

QUESTIONS FOR REVISION

1. What is food? Mention a perfect food, and give its composition.
2. Give a number of simple experiments by which you can distinguish between albumin, fat, and sugar.
3. Why is milk considered to be a perfect food?
4. Enumerate the food substances which occur in milk, cheese, and bread.
5. Give the colour tests for (*a*) proteins, (*b*) fats, (*c*) starch, (*d*) grape sugar.
6. How does gelatin differ from albumin and from a fat?
7. Give a classification of the food substances, with examples.
8. Give the fuel value and digestibility of the food substances.
9. What amount of food must be present in a diet for (*a*) ordinary work, (*b*) hard work?
10. What is an article of food, and what does it contain?

CHAPTER XIV

THE DIGESTION OF THE FOOD SUBSTANCES

THE food substances, in their passage through the alimentary canal, are changed by the action of the **enzymes** or **ferments** present in the digestive juices, which render them soluble and diffusible. This process is known as **digestion.** The food substances can only be utilised in the body when they enter the blood stream, and they must therefore be rendered soluble so as to dissolve in the fluid which the alimentary canal contains, and diffusible so as to pass through the mucous coat into either the blood-vessels or lymphatics.

ENZYMES

An enzyme is a colloid, and either it will not pass through a membrane or does so with extreme slowness. It is of the nature of a protein, and acts as a **catalystic** agent, which can change the chemical nature of a food substance. A chemical catalyst is a substance which can alter the rate of change which bodies undergo, but cannot as a rule commence the change. If cane sugar is boiled with sulphuric acid, it is inverted, or split into two invert sugars. This is a case of the action of a chemical catalyst which carries or condenses water on the molecule of the sugar.

Enzymes differ from chemical catalysers in being able to commence the change which bodies such as

the food substances undergo. In some cases this may be due to the addition of water, as in the conversion of starch into sugar by ptyalin, or by splitting up its molecule into simpler forms, as in the change of peptones into tyrosin and leucine.

The action of the digestive enzymes on the food substances are:—

Enzymes.	Formed by	Action on	Forms	In Part of Alimentary Canal.
Pepsin . .	Gastric glands.	Proteins.	Peptones.	Stomach.
Trypsin . .	Pancreas.	Proteins.	Peptones, tyrosin, and leucine.	Small intestine.
Erepsin . .	Glands of mucous coat of small intestine.	Fibrin, casein, and peptone.	Tyrosin and leucine.	Small intestine.
Steapsin . .	Pancreas.	Fats.	Fatty acids and glycerine.	Small intestine.
Ptyalin . .	Salivary glands.	Starch.	Dextrin and maltose.	Mouth and stomach.
Amylopsin .	Pancreas.	Starch.	Dextrin and maltose.	Small intestine.
Invertase . .	Intestinal glands.	Cane sugar.	Glucose or grape sugar.	Small intestine.
Maltase . .	Intestinal glands.	Maltose.	Glucose.	Small intestine.
Lactase . .	Intestinal glands.	Milk sugar.	Glucose.	Small intestine.

Digestion changes the proteins into peptones, tyrosin, and leucine; the carbohydrates into glucose; the fats into fatty acids and glycerine, or forms emulsions or soaps.

SECRETORY GLANDS.—The glands which play such an important part in digestion are the salivary glands, gastric glands, pancreas, liver, and intestinal glands.

Experiment 38.—(1) Obtain a salivary gland from a dead rabbit or pig. Note (i) that the gland is like a bunch of grapes enclosed in a bag, and the capsule is made of connective tissue. (ii) Find the duct along which the saliva passes into the mouth, and trace it back into the gland, carefully removing the capsule. A number of small ducts will be seen to enter the main duct. (iii) Try and unravel it, and expose the lobes to view. (iv) Cut across a lobe, and if possible find the lobules. (v) Tease out a piece of the gland in a drop of salt solution, and make out the cells with their granules.

(2) If possible examine with a microscope a section of a salivary gland, and make out the small ducts which enter the lobules, noting the difference between the cells which line the two structures.

THE SALIVARY GLANDS.—The saliva is secreted by the numerous glands in the mucous membrane of mouth and tongue, and the three pairs of salivary glands. The watery fluid, the saliva, as passed into the mouth, is a mixture of the secretions from the glands enumerated above, but the greater portion comes from the glands described below.

(1) The PAROTID SALIVARY GLANDS, which are placed just below and in front of the ears. A duct collects the saliva from the right parotid gland, which opens into the mouth opposite to the second molar tooth on the right side. The duct from the left parotid

glands opens on the left side of mouth, and opposite to the second molar tooth.

(2) The SUBLINGUAL SALIVARY GLANDS are placed in the floor of the mouth beneath the tongue.

(3) The SUBMAXILLARY SALIVARY GLANDS occupy the angles beneath the submaxillary or lower jaw bones. The **ducts,** from both the sublingual and

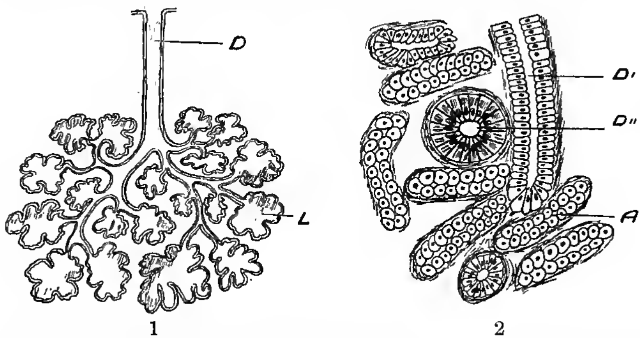


FIG. 68.—1, Diagram of salivary gland. *D*, main duct of; *L*, lobe of gland. 2, A portion of section across a salivary gland. *D'*, duct in longitudinal section; *D''*, in transverse section; *A*, albuminous alveoli.

submaxillary glands, open in the floor of the mouth beneath the tip of tongue.

Each gland is made up of a number of lobes, and these are surrounded by a well-developed sheath or capsule, through which blood-vessels and lymphatics enter and leave the gland, and the small collecting tubules which come from the lobes discharge their contents into the main duct. Each lobe is built up of a number of small lobules, each of which contains numerous secreting cells, and these form saliva from the substances present in the blood. The number of granules present in the secreting cells depends upon the

condition of the gland. If the gland has been actively secreting, only a few granules will be present, but after a resting period they are loaded with granules, which are the forerunners of the substances present in the saliva. Secretion is a method of growth, for during the resting period the gland-cells take from the blood materials, and convert these into their own substance, and into the granules which they contain. The granules are discharged during secretion, and these, along with water which passes from the blood-vessels, form saliva. The enzyme ptyalin does not exist as such in the secretory cells, but only the forerunner or mother enzyme, which is changed during secretion into ptyalin.

SALIVA.—Mixed saliva is the first digestive juice to come in contact with the food, and its average composition is:—

Water	99·29 parts per 100.
Ptyalin, which is an enzyme . .	0·71 parts per 100.
Mucin, which is a stringy protein substance	
Globulin, a protein	
Salts	

It has recently been demonstrated that its composition will vary with the nature of the food which enters the mouth. With dry food the secretion is more watery, but with meat thick and viscid.

It is a watery fluid in which the ptyalin, mucin, and the other constituents are dissolved. The mucin is a stringy substance which coats the masticated food to form a bolus, and by lubricating the food and binding the particles together aids swallowing. The ptyalin acts on starch, and changes it into maltose or malt sugar. It can only act on starch in a neutral or alkaline solution, and at a temperature of from 35° to 40° C. If the temperature of the saliva is raised to 70° C., its

action ceases. The saliva not only changes starch into sugar, but keeps the mucous membrane of the mouth moist and soft, softens the food, and dissolves any soluble constituents which may be present, such as sugar and salt. If acid substances are present in the food, the action of ptyalin is retarded, or it ceases to act on starch. In addition to the functions of saliva enumerated above, it probably acts in other ways in preparing the food for digestion in the remainder of the alimentary canal, for if a person has to be fed by passing the food into the œsophagus instead of by the mouth, it is necessary that it should be masticated first, or there will be a loss of weight.

Experiment 39.—Collect some saliva in a clean test-tube, and test its reaction with damp litmus papers. What is the reaction of saliva? The saliva can be made to flow freely by using chewing-gum, or by filling the mouth with the vapour of ether.

(1) Now obtain five clean test-tubes, and number them 1 to 5. Arrange a water-bath so that the water can be kept at a uniform temperature of about 100° F. (38° C.). Make some thin starch paste. This can be done by boiling half a gram of starch in 100 c.c. of water, and the best results can be obtained when the paste is used at a temperature of 38° C. Collect some saliva as in the last experiment.

(2) Place a little starch paste in each test-tube, and a little iodine solution, so as to give it a pale blue colour. (i) Set tube 1 in the water-bath, and use it as a control for any change of colour which may take place in the other tubes. (ii) Add to tube 2 a little saliva, and set in the water-bath. (iii) Place a few drops of hydrochloric acid into tube 3, and some saliva. Set in the water-bath. (iv) Boil some saliva, and add

to tube 4, shake, and keep in water-bath. (v) Prepare another test-tube in a similar manner to number 2, but keep in a tumbler of cold water to which a small piece of ice has been added.

At the end of one hour examine the tubes, and note results. The contents of tube 1 will show the same colour as when placed in the water-bath, while the starch in tube 2 will have lost its blue colour, and is of a watery consistency. The tube which contains the hydrochloric acid has undergone no change, and this is also true of the tube which contained the boiled saliva, while the one kept in the cold water still retains its characteristic blue colour. The latter tube should now be placed in the water-bath for one hour, when the blue colour slowly disappears.

CONCLUSIONS.—The iodine method of distinguishing the change produced in starch by the action of saliva depends upon the change in colour as the starch is converted into sugar, and the experiments performed show that the action of ptyalin can only be performed when suitable conditions are present. These are (1) a temperature of that of the human body (see tube 5); (2) an alkaline solution is necessary to work in (see tube 3); (3) a high temperature, such as that of boiling, destroys its action (see tube 4).

THE SECRETION OF SALIVA.—The secretion of saliva is under the control of the nervous system, and the nerves bring impulses which act at once on the gland cells, which discharge their contents into the lumen of the alveoli. The small arteries dilate, and water passes from the blood into the gland, where it mixes with the substances from the gland cells to form

saliva. The nervous centre which governs secretion is influenced by the nature of the food which enters the mouth, for the observed variation in composition depends upon the character of the substances which touch the mucous membrane of mouth and tongue.

MASTICATION OF FOOD.—The front teeth are used to bite off the food, and the bicuspids and molars to grind it up. The action of the teeth are aided by the movements of the lower jaw and tongue, which bring the food between the teeth and against the gums and hard palate. Food should be eaten slowly, so that the saliva can moisten and soften it, and if well masticated it is prepared for digestion in the stomach.

HOW TO EAT.—The rules which are given below should form the basis of the conduct of the individual in taking food:—

(1) The food should be eaten slowly, so that the saliva can moisten and soften it.

(2) The food should be well masticated, so that it is well prepared for digestion in the stomach.

(3) The food should not leave the mouth until the above rules are fulfilled.

(4) The food should be eaten dry, and liquid should not be taken until near the end of a meal.

The food passes across the pharynx, and the muscular coat of the œsophagus by its contraction forces it into the stomach. If the food has been well masticated and mixed with the saliva, the ptyalin will for a period of 20 to 40 minutes act on the starch, changing it into maltose, and this goes on until the hydrochloric acid acts on the enzyme and stops its action.

Experiment 40.—(1) Obtain from a butcher a fresh pig's stomach, and remove a portion of the mucous

coat from the cardiac end. Tease up in salt solution, and examine with the microscope. Find with the low power (i) gastric glands; (ii) the secretory cells; these consist of two kinds, the **principal** or **chief cells** and the **ovoid** or **parietal cells** (Fig. 69).

(2) Now proceed in a similar manner to examine a piece of the mucous coat from the pyloric end. The gastric glands from the pyloric end are lined with chief cells only, and thus no ovoid cells will be seen.

(3) If a prepared vertical section of the cardiac end of stomach can be obtained, examine with the high power, and look for (i) the mouth of gland, into which the ducts of several glands may open; (ii) the neck; (iii) the body of a gland. Examine the cells, and note that the duct is lined with flat cells, while the body contains numerous tall columnar ones, which are known as **chief cells,** and a few scattered ones, which are fixed on the basement membrane; these are the **ovoid** or **parietal cells.**

(4) Proceed in a similar manner to examine a vertical section of the wall of pyloric end of stomach, and find (i) the mouth of a gland; (ii) the body, which is lined with chief cells.

Experiment 41.—(1) Obtain some gastric juice. This can be prepared by scraping the mucous coat of the stomach of a pig which has been kept in a damp cloth for some time; place the scrapings in glycerine, and shake from time to time. At the end of a week pour off the glycerine, and add to it a 0·2 per cent. solution of hydrochloric acid. This contains gastric juice. Another way is to use Benger's Liquor Pepticus, to which a 0·3 per cent. solution of hydrochloric acid has been added.

(2) Test the solution of gastric juice with litmus

paper. What is the result, and how does its reaction differ from that of saliva?

Experiment 42.—(1) Place a little hard-boiled white of egg or fibrin in the bottom of a test-tube, and cover with distilled water. Number the tube and keep it in a water-bath at a temperature of about 100° F. (40° C.). This is the control experiment.

(2) Cover a similar piece of hard-boiled egg with some prepared gastric juice, and keep in the water-bath.

(3) Prepare a similar tube to number 2, but boil the contents, and keep in a water-bath. At the end of an hour examine the tubes, and note the results. Write a full description of the results, and state the conclusions which you draw from the experiments.

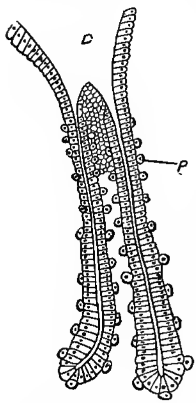


FIG. 69. — Cardiac gastric glands. *D.* duct; *P.* parietal cell. Note the numerous chief cells.

Experiment 43.—Test a portion of the contents of tube 2, which was used in the last experiment, with a trace of copper sulphate solution and a little strong sodium hydrate solution. On boiling, a pink tint will be obtained if peptones are present. This is a colour test for peptones. Ordinary proteins give a violet colour with sodium hydrate solution and copper sulphate.

Peptones are proteins which will diffuse or pass through a membrane.

THE GASTRIC GLANDS.—In the mucous coat of the stomach there are numerous gastric glands, which secrete gastric juice. Each gland possesses a mouth

where it opens into the cavity of the stomach, a body or secreting portion, and a constriction between the above, which is known as the neck. The collecting portion of the gland is lined with flat cells, which contain very few granules, but the secreting portion contains columnar cells, which during the resting stage are loaded with granules, and the cells bulge to such an extent that the lumen or opening is obliterated. There are

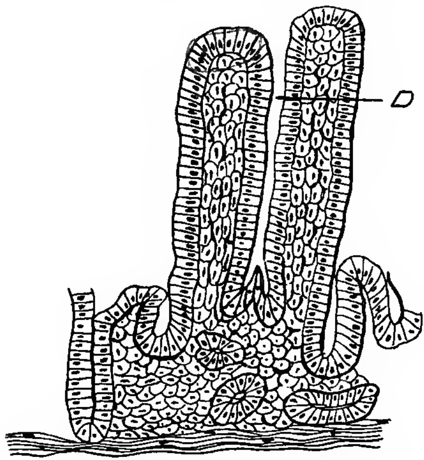


FIG. 70.—Vertical section of pyloric end of stomach, showing pyloric gastric glands. *D.* duct of gland.

two kinds of gastric glands (1) those found at the cardiac end of the stomach, and (2) those at the pyloric end. The bodies of the glands at the cardiac end of stomach contain two kinds of cells, the **principal** or **chief** and the **parietal** or **ovoid** cells; while the secreting portion of the pyloric glands are lined with one kind of cell, the chief cells.

COMPOSITION OF GASTRIC JUICE.—The gastric glands secrete gastric juice from the blood, and

the secreting cells form the mother enzymes, and these are changed into pepsin and rennin when secretion commences. On food entering the stomach the cells become active and discharge their secretions into the ducts, where it is changed into gastric juice, which contains:—

	Per Cent.
Water	99·44
Pepsin, an enzyme which converts proteins into peptones; Rennin, a milk-curdling enzyme	0·32
Hydrochloric acid, which is formed by the parietal cells of the cardiac glands	0·20
Salts	0·04

The hydrochloric acid acts on the proteins and changes them into acid proteins. The pepsin is an enzyme which changes the acid proteins into peptones, and rennin curdles the milk.

THE FOOD IN THE STOMACH.—The stomach in the living body is divided by a contracted band of muscle into two portions; the largest division is at the cardiac, and the smallest at the pyloric end. The food passes from the œsophagus into the cardiac end of stomach, where it accumulates, and the contraction of the muscular coat mixes it with the gastric juice. As digestion proceeds and soluble substances are formed, they are propelled into the pyloric end, where more gastric juice is mixed with them. At last the portion is fit to enter the small intestine, and the sphincter muscle at the pyloric end relaxes so that the chyme can enter the duodenum. This process is repeated again and again until the whole of the contents of the stomach passes into the small intestine.

THE SECRETION OF GASTRIC JUICE.—Even before food enters the stomach gastric juice is passed

from the glands, and the secretion of this is due to the sight of food acting through the nervous system. From the food which enters the stomach this portion of the gastric juice forms substances which act on the mucous membrane at the pyloric end, the cells of which produce a chemical substance known as **secretin.** The secretin on absorption into the blood stimulates the gastric glands, so that as long as food remains in the stomach gastric juice is produced for its digestion. Thus the first portion of the gastric juice is secreted through the action of nervous impulses which act on the gastric glands, while the production of the remainder of the gastric juice is due to the action of the secretin which is formed by the cells of the mucous membrane.

The secretin is a chemical messenger which influences its appropriate gland cell, and it differs from an enzyme in not having its activity destroyed by a high temperature. The gastric secretin only acts on the secreting cells in the gastric glands.

Experiment 44.—(1) Obtain from a butcher a fresh sweetbread or pancreas (if possible from the pig), and note that it is a long racemose gland of a milky white colour. (i) Now find its duct, and trace it back to the lobes of the pancreas. There is a small duct for each lobe, and these empty into the main duct. (ii) Remove the capsule and unravel one of the lobes. Tease a little in salt solution, and examine with the microscope. Look for collecting tubules and lobules.

(2) Examine a prepared section of the pancreas, and make out the general structure, dwelling especially on the characters of the gland-cells.

Experiment 45.—Obtain from a butcher the pancreas of a recently-killed sheep or pig, wrap it up in a damp cloth, and keep it in a warm room for twenty-four hours.

With a sharp knife mince it up, place it in a jar, and cover with glycerine. Shake from time to time, and at the end of four days decant off the glycerine. This solution contains pancreatic juice. Test its reaction with litmus paper. Another way to obtain pancreatic juice is to use Benger's Liquor pancreaticus.

Experiment 46.—(1) Take some pancreatic juice and place a little in a test-tube, add to it a little bile, and drop in a little piece of hard-boiled white of egg. Keep in a water-bath for an hour at the temperature of the body (about 100° F.). Examine the hard-boiled egg to see if it has changed. What is the result?

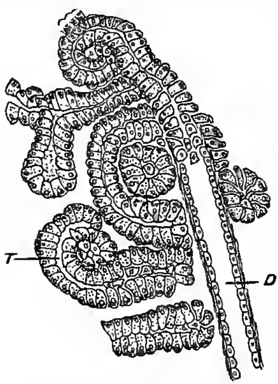


FIG. 71.—Section of pancreas. *D*, duct; *T*, lumen of tubule surrounded with secreting cells.

(2) When the whole of the white of egg has been dissolved (Experiment 42), empty into a dialyser,[1] and let it stand in distilled water for a few hours. Test a little of the distilled water for peptones. What is the result?

(3) To a small quantity of the pancreatic juice and bile add a few drops of oil, shake, and keep warm. The fat is emulsified.

(4) Apply the iodine test to a thin starch paste, and add to it some pancreatic juice and bile. Keep in a water-bath at the temperature of the body. State the results and the conclusions you draw from this experiment.

THE PANCREAS.—The pancreas is a long white gland, which is found just behind the stomach with its head fitting into the loop formed by the duodenum;

[1] A sausage skin will make a good dialyser.

it is about 8 inches long, and consists of a number of lobes, which are surrounded by a capsule. Its duct opens into the common bile duct, and its secretion enters the duodenum along with the bile. Each lobe is made up of a number of tubular alveoli, which are lined with secreting cells, and these form from the blood the pancreatic juice. The mode of formation of the secretion is similar to that of gastric juice and saliva. The cells in the resting gland contain numerous granules, and these are discharged along with water to form the secretion. The mother enzymes on passing from the cells into the lumens of the alveoli are changed into the different enzymes.

THE PANCREATIC JUICE.—The pancreatic juice is alkaline, and contains both organic and inorganic solids. Its average composition is:—

Composition of Pancreatic Juice.		Ferments which act on Food Substances.	Salts.
	Per Cent.		
Water . . .	97·6	Trypsin, which acts on proteins.	Common salts.
Ferments, &c.	1·8	Amylopsin, which acts on starch.	Potassium chloride.
Salts	0·6	Steapsin, which acts on fats.	Phosphate of sodium, &c.
(After Halliburton.)		A milk-curdling ferment.	

The action of the ferments present in the pancreatic juice is given in the table on p. 166.

THE SECRETION OF PANCREATIC JUICE.—The secretion of pancreatic juice does not seem to be under the control of the nervous system, but to be due to the formation of **secretin** by the epithelial cells which line the small intestine. From the work done by Professor Starling and Mr. Bayliss, it seems certain that the acid chyme on entering the duodenum acts on

the epithelial cells which line its walls, and form secretin from a pre-existing substance, which they named **pro-secretin.** The secretin on absorption into the blood acts on the gland cells in the pancreas, and they secrete pancreatic juice.

INTESTINAL GLANDS.—On p. 136 it was noted that the mucous coat in the duodenum contains Brunner's glands, and these along with the glands of Lieberkuhn form the **succus entericus** or intestinal juice. Brunner's glands resemble in certain respects the pyloric gastric glands, and the glands of Lieberkuhn are tubular depressions which are found throughout the small and large intestines. The intestinal juice contains invertase, which acts on cane sugar, changing it into glucose, and maltase, which changes maltose into glucose. In addition to the above enzymes it may contain lactase, which converts milk sugar into glucose. The secretion of the intestinal juice seems to depend upon **secretin** in a similar way to gastric and pancreatic juice.

Experiment 47.—(1) Obtain from the butcher an ox-gall, and empty the bile into a beaker. Test a little of this with litmus papers. What is the result?

(2) Place a little bile in a test-tube, and add to it a little olive oil. Shake well and keep warm. The bile salts convert the liquid into an emulsion, but it is not permanent.

(3) Fold two filter papers, insert them into funnels, moisten one filter paper with bile and the other with water. Pour a little oil into each. Note what takes place. State the results of the above experiments and the conclusions you draw from them.

THE BILE.—On p. 143 the structure of the liver

cells and their functions were noted, and we have now to consider the composition and functions of the bile.

Water	86 parts.
Bile salts	13 „
Bile pigments	
Mucin	
Inorganic salts	1 „
	100

The secretion of bile is governed by secretin in a similar way to gastric, pancreatic, and intestinal juice.

THE FUNCTIONS OF BILE.—The bile performs several useful functions in connection with digestion; these are:—

(1) The alkalinity of the bile helps to neutralise the acidity of the chyme when it enters the duodenum, and it **doubles** the action of the trypsin and amylopsin in the pancreatic juice.

(2) It has a very slight emulsifying action on fats, and probably aids in the production of soaps in the small intestine, but the mixing of the bile with the pancreatic juice increases the action of steapsin **three-fold** in splitting fats into fatty acids and glycerine. This action is probably due to the bile salts.

(3) It acts on the mucous coat of the intestine, and aids in the absorption of fats (Experiment 47). This action is also due to the bile salts.

(4) It helps to lubricate the interior of the intestine, and promotes the regular action of the bowels.

(5) It has a slight antiseptic property, which prevents the decomposition of the food during its passage through the intestine.

THE FOOD IN THE SMALL INTESTINE.—The acid chyme on entering the duodenum is mixed with the bile, pancreatic and intestinal juices; these neutralise its acidity. The proteins are changed by the action of

trypsin into peptones, tyrosin, and leucin. The fats are changed by steapsin into fatty acids and glycerine, and emulsified. The amylopsin converts starch into dextrin and maltose, the latter being changed by maltase into glucose. At the end of a period, which varies in different cases, the remnants of the food pass through the ileo-cæcal valve into the large intestine.

THE LARGE INTESTINE.—The food as it passes through the ileo-cæcal valve is a watery fluid about the same consistency as chyme, for if water and many of the soluble materials have been absorbed, this has been counterbalanced by the secretions which have been poured in. It contains water, and the soluble materials remaining are absorbed in the large intestine, and an acid fermentation is set up by bacteria. The remainder of the food becomes more or less solid, and takes on the characteristic smell and appearance of the fæces.

QUESTIONS FOR REVISION

1. What is an enzyme? Enumerate a few enzymes.
2. During digestion the food substances are converted into a few simple (comparative) substances. What are they?
3. Enumerate the number, positions, and use of the salivary glands.
4. Describe the structure of a salivary gland.
5. How can you prove that saliva can change starch into sugar?
6. How and when is saliva secreted by the salivary glands?
7. Give a set of rules as a basis of conduct in eating.
8. Describe the structure of (*a*) the cardiac, and (*b*) the pyloric gastric glands.
9. What is the composition of gastric juice? When and how is gastric juice secreted?
10. Give a brief account of the action of gastric juice on food.
11. What is the pancreas? What are its functions?
12. Enumerate the properties of pancreatic juice.
13. How does the secretion of saliva differ from that of pancreatic juice and bile?
14. What are the functions of bile?
15. Follow from the mouth to the rectum the changes which a meal of mixed food undergoes during digestion.

CHAPTER XV

THE ABSORPTION OF THE FOOD SUBSTANCES

THE ACTION OF ENZYMES. — The enzymes in the digestive juices perform the important function of changing colloid food substances into crystalloid bodies, which are soluble and diffusible. They can perform this important function in the presence of either acids or alkali, and at the normal temperature of the body. A high temperature destroys this action (p. 171), and one lower than that of the body retards it. For each enzyme there is an **optimum** temperature at which the change is most rapid, and it possesses a maximum and a minimum temperature above and below which no change takes place. They are probably colloid bodies, and either will not diffuse or do so with extreme slowness. It must be distinctly understood that digestion is a process of enzyme action, and that each particular one requires certain conditions before performing its important function. The most remarkable thing in digestion is the few compounds produced from the food substances ingested, for most of the proteins are changed into peptones, the carbohydrates into glucose, and the fats into fatty acids and glycerine, or are emulsified.

THE CONDITIONS OF THE PROTEINS IN THE SMALL INTESTINE.—The native proteins in the food when it enters the alimentary canal are insoluble and indiffusible, and in the stomach they may

be changed by the hydrochloric acid into acid proteins. The enzyme pepsin changes a certain proportion of the acid proteins into peptones. Peptones are proteins which will diffuse or pass through a membrane.

The chyme, when it passes into the small intestine, contains peptones, acid proteins, and probably native proteins. The alkali in the pancreatic juice acts on the proteins, and changes them into alkali proteins. The enzyme trypsin converts these into peptones, and some of the latter into tyrosin and leucine. By the action of the enzymes enumerated above, most of the proteins are changed into soluble and diffusible substances which are fit to enter the blood stream.

THE CONDITION OF THE CARBOHYDRATES IN THE SMALL INTESTINE.—The carbohydrates, starch, cellulose, glycogen, and cane sugar, undergo certain changes before they can enter the blood stream. Some of the starch in the food is changed by the enzyme ptyalin in the saliva into sugar, but this action is prevented in the stomach by the hydrochloric acid, for it can only act in either a neutral or an alkaline solution. In the small intestine the remainder of the starch is converted into sugar by the amylopsin in the pancreatic juice. Raw starch is a colloid, and the sugar is a crystalloid which is diffusible.

The glycogen may undergo a similar change during digestion.

A very small quantity of the cellulose in the food may be converted into sugar. This is due to the action of bacteria and marsh-gas.

The cane sugar in the food is inverted either by the action of the hydrochloric acid in the stomach, or by the invertine in the intestinal juice into glucose or

grape sugar. The sugar is now ready to enter the blood stream, and, like the peptones, is dissolved in the fluids in the small intestine.

THE CONDITION OF THE FATS IN THE SMALL INTESTINE.—The fats are compounds of fatty acids and glycerine, and as they enter the alimentary canal they will not mix nor dissolve in water. In the mouth they are broken up in the process of mastication and melted. The fatty tissue in the

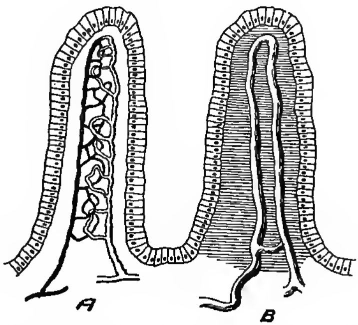


FIG. 72.—A pair of villi from small intestine (partly diagrammatic). *A*, capillary network of villus with small artery and vein ; *B*, radical lacteal of villus.

stomach is changed by the pepsin, which dissolves off the protein coverings, and the fat globules are set at liberty. These float in the chyme, and enter the small intestine. The bile and pancreatic juice changes the acid chyme into alkaline chyme, in which the enzymes present in the pancreatic juice can act.

The enzyme steapsin splits some of the fats into fatty acids and glycerine, and, along with the alkaline substances in the bile, emulsifies the remainder. These will mix with the fluids in the small intestine, and can enter the lacteals (p. 117).

THE VILLI.—In Chapter VIII., in considering the structure of the small intestine, we noticed that the mucous coat was thrown into minute finger-like projections, which receive the name of **villi** (p. 136). Each villus is covered with a layer of cells which form an epithelium, and in the centre a more or less club-shaped body can be seen, the **radical-lacteal** (p. 117). The rest of the villus consists of adenoid tissue, which contains blood-vessels and lymphocytes. Two small arteries supply blood to the capillaries, which run just beneath the epithelium, and from these it is removed by small veins. The villi are the special organs for the absorption of the diffusible food substances.

THE ABSORPTION OF FOOD SUBSTANCES.—The food in the small intestine contains peptones and grape sugar. These pass through the epithelium, which covers the villi, and enter the blood in the capillaries beneath. The blood from the villi enters the portal vein (p. 144), and reaches the lobules of the **liver,** where it is rendered suitable to enter the general circulation.

The fats pass through the walls of the villi and enter the lymph in the radical-lacteals. The lymph is changed into chyle (p. 117), and this passes along the lymphatic vessels to the **thoracic duct,** which joins the venous system at the junction of the subclavian and jugular veins on the left side of the neck (p. 119).

The diffusible products of digestion find their way into the general circulation along two paths, the peptones and sugar passing through the liver to the hepatic vein and inferior vena cava, and the fats through the thoracic duct to the veins of the neck and superior vena cava.

The peptones, on passing through the walls of the

capillaries, are changed into ordinary proteins, such as serum albumen and globulin. Peptones are of no service in the nutrition of the body, and if they are injected into the blood stream, they leave unaltered in the urine. This seems to show that all the changes the proteins undergo during digestion are to make them diffusible.

In a similar manner the cane sugar must be changed into grape sugar, for if the former is injected into the blood stream, it leaves unchanged in the urine.

QUESTIONS FOR REVISION

1. What is an enzyme? Give an account of the characters of enzymes.
2. How are the proteins rendered fit to enter the blood stream, and what are the end products of enzyme action on the proteins?
3. Explain how the carbohydrates are prepared for absorption in the small intestine.
4. Enumerate the end products which the enzymes form from proteins, fats, and carbohydrates.
5. Describe the structure of an intestinal villus.
6. Trace the fats from their entry into the alimentary canal by the mouth until they reach the general blood stream.
7. Follow the proteins and carbohydrates from the mouth until they enter the general circulation.

CHAPTER XVI

THE LUNGS AND RESPIRATION

RESPIRATION. — Every living animal and most plants require free oxygen, and this, acting on the protoplasm, produces energy. The very minute forms of life have no special organs concerned in obtaining oxygen, for it can enter at all points; even the earthworm breathes through its skin, which is very thin, and the lug-worm, which lives in the sea, has thin outgrowths of the skin, which perform a similar function and are known as gills.

In fishes the membranes which are concerned in the interchange between the blood and the air dissolved in the water are folded to form gills. In air-breathing animals the membranes used for breathing are folded to form lungs, and these are adapted for the interchange of gases between blood and air.

The simplest type of lung is met with in mud fishes which live in the rivers of Africa and Australia; the rivers dry up during the summer, and these fishes bury themselves in the mud, breathing through a swim-bladder, the walls of which contain blood-vessels. The newt and the frog have the breathing membrane folded so that the blood-vessels which it contains can be exposed to the air in the sac or sacs, and this condition is greatly exaggerated in the lungs of man. The breathing membrane in the human lungs would cover an area of one hundred square yards if unravelled and spread out. The tissues are always

taking oxygen from the blood, and returning carbon dioxide to it. From the oxidation which goes on in the tissues energy is produced, which is expressed in the active life of man. Nearly the sole pathway into and from the blood is by the lungs, and the interchange between the blood and atmosphere is known as **respiration**. The organs concerned

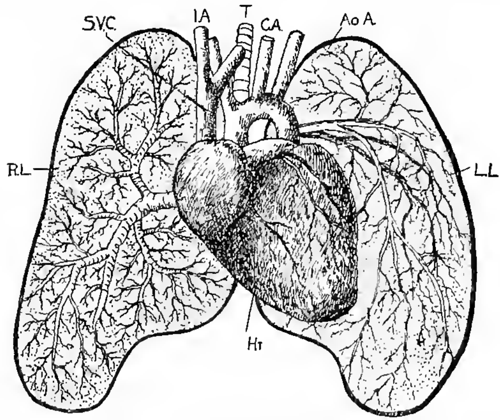


FIG. 73.—Front view of human heart and lungs. *R.L.* right lung; *L.L.* left lung; *Ht.* heart; *S.V.C.* superior vena cava; *I.A.* jugular vein; *Ao.A.* aortic arch; *C.A.* carotid artery; *T.* trachea. The lungs have been dissected to show the bronchial tubes and blood-vessels.

in respiration are the air-passages, lungs, and the structures which form the walls of the thorax or chest.

THE AIR-PASSAGES

The air-passages which are concerned in breathing are the nose, pharynx, windpipe, bronchi, bronchial tubes, and smaller tubes which end in infundibula. The structure of the bronchial tubes and infundibula will be dealt with when the structure of the lungs

is considered, and the larger passage now calls for consideration.

THE NOSE.—The nose consists of bone and cartilage which is covered with skin, and its lower passages are lined with red mucous membrane. It opens to the exterior by the anterior nares, and to the pharynx through the posterior nares. Some of the nasal bones are folded to form pouches, and these are also lined with mucous membrane. The nose is abundantly

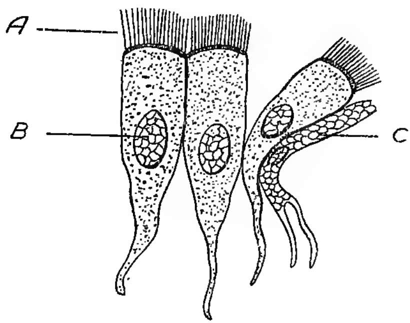


FIG. 74.—Ciliated cells from trachea. *A*, cilia; *B*, nucleus of cell; *C*, mucous cell.

supplied with blood-vessels, and the blood they contain warms the air during its passage from the anterior to the posterior nares.

The respiratory mucous membrane which lines the nose is made up of a basement of connective tissue and several layers of cells. The outer cells are columnar in shape and ciliated, while the lower ones are generally oval. All the cells are united by cement substance, and as the outer ciliated cells break away, the lower ones change their shape, become ciliated, and take their place. Each surface cell of the mucous membrane bears from 10 to 30 filiform processes, which

receive the name of cilia. The cilium bends quickly into a sickle-like shape, and then slowly straightens. It averages 8 double movements in a second, and may increase to as many as 20 per second. All the cilia on one cell bend in the same direction, and act in such a way that substances are swept towards the anterior nares. The mucous membrane also contains numerous glands which secrete mucus, and this arrests many of the solid particles which enter with the air. The accumulation of solid particles, such as dust and bacteria, on the mucous membrane promotes the action of the glands, and thus leads to an increased production of mucus, as during colds. This is Nature's method for the removal of the intruders.

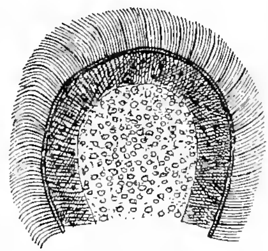


Fig. 75.—A portion of the gill of the sea mussel showing the fringe of cilia.

The upper nasal cavities are concerned with the sense of smell, and this important function enables injurious substances in the air to be detected. The smell of stuffy rooms, the pungent fumes of ammonia, and the escape of coal gas may be mentioned as examples.

In ordinary breathing the air should always pass through the nose, as the mucous membrane filters or removes any solid particles present, and the blood circulating in the blood-vessels warms the air.

Experiment 48.—(1) Obtain from a fish-dealer a few fresh mussels and open one so as to expose the yellowish gills. Remove with a pair of sharp scissors a piece of the yellowish gills, and mount it in a drop of the fluid from the interior or mantle cavity of the

mussel. Examine with the low power, and find the rounded gills. Note the movements of the cilia which sweep along the particles in the mounting fluid. Run under the cover-glass a drop of chloroform;

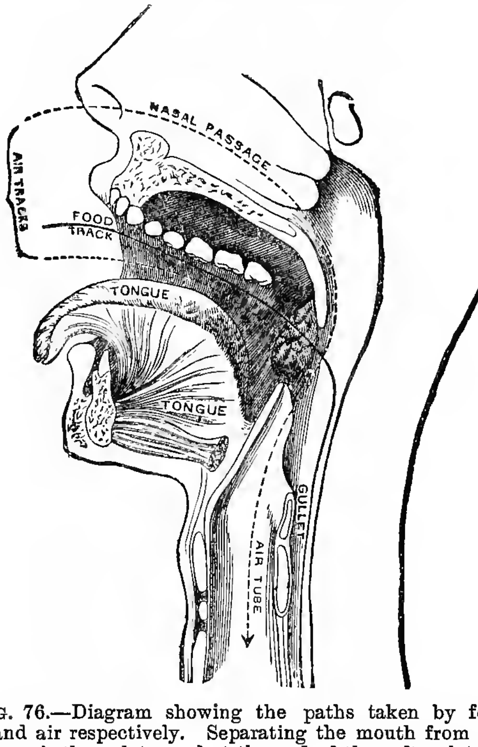


FIG. 76.—Diagram showing the paths taken by food and air respectively. Separating the mouth from the nose is the palate, and at the end of the soft palate is the right tonsil.

the movements cease, and the cilia can be distinctly seen if the high power is used.

(2) Open the mouth of a recently-killed frog, and scrape the roof of the mouth with a clean knife. Mount the scrapings in a drop of salt solution.

Examine and note the shape of the ciliated cells. Some of the cells may break away from the main mass and swim in the mounting fluid. Stain a similar preparation with a drop of eosin, and make sketches of the cells.

THE PHARYNX.—The posterior nares open into a funnel-shaped cavity, the **pharynx**. It is lined on

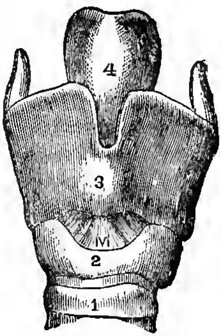


FIG. 77.—Diagram of front view of larynx. 1, top of trachea; 2, circoid cartilage; 3, thyroid cartilage; 4, epiglottis; *M.* membrane between the thyroid and circoid cartilages.

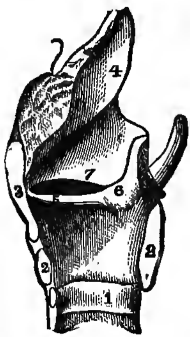


FIG. 78.—Diagram of larynx with the left side removed. 1, top of trachea; 2, 2, circoid cartilage; 3, thyroid cartilage; 4, epiglottis; 5, true vocal cords; 6, arytænoid cartilage, which rests on the circoid cartilage; 7, false vocal cords.

its upper surface with ciliated mucous membrane, which is similar in structure to that lining the lower nasal cavities, and it probably performs the same functions. The lower portion is lined with ordinary mucous membrane. The mouth and nose open into the pharynx on its anterior surface, while the œsophagus and glottis open into it behind. The opening of the glottis is protected by a lid-like epiglottis.

N

THE WINDPIPE.—The tube which connects the pharynx with the lungs is known as the windpipe. It consists of an upper portion, the larynx, and a lower, the trachea. The opening into the larynx is known as the glottis, and a lid-like structure stands over it; this is the epiglottis. The larynx or voice-box is made up of cartilages, and it contains the vocal cords. The trachea commences at the base

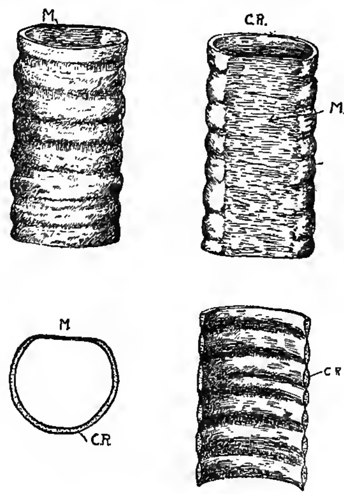


FIG. 79.—Diagrams of portions of trachea. *C.R.* C-shaped rings of cartilage; *M.* muscle.

of the larynx, and ends where it divides to form the bronchi. The windpipe is lined with ciliated mucous membrane, and the trachea is built up of imperfect rings of cartilage. The ends of the cartilaginous rings are joined by muscles, and these by their contraction can slightly constrict the trachea, and thus help to force any mucus which may be present towards the anterior nares. The cartilages are joined by

connective tissue, and the whole is covered with a fibrous sheath.

THE BRONCHI AND BRONCHIAL TUBES.—Both the bronchi and bronchial tubes have the same general structure as the trachea, but the cartilaginous rings are more irregular in shape and arrangement. The formation, structure, and arrangement will be fully demonstrated in Experiment 49.

THE INFUNDIBULA.—The bronchial tubes end in very small tubes with thin walls which are without

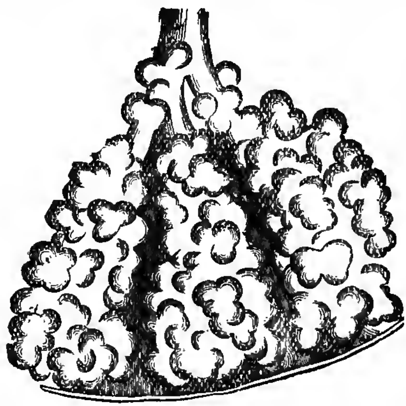


FIG. 80.—A group of infundibula from human lung, showing air-tubes and alveoli.

cartilages. Each small air-tube opens into a little swelling which is known as an infundibulum, and which is divided by septa or partition walls into alveoli or air-cells. The wall and septa of the infundibulum contain numerous large capillaries, and the blood which they contain is separated from the air inside the infundibulum by a very thin membrane. It is in the infundibula that the interchange of gases

takes place between the air in the alveoli and the blood in the capillaries.

THE LUNGS.—The lungs are built up of infundibula, air-tubes, bronchial tubes, bronchi, and blood-vessels, the whole being surrounded by connective tissue to form right and left lungs. Each lung is surrounded by the pleural membrane, the visceral layer clinging tightly to it, while the parietal layer

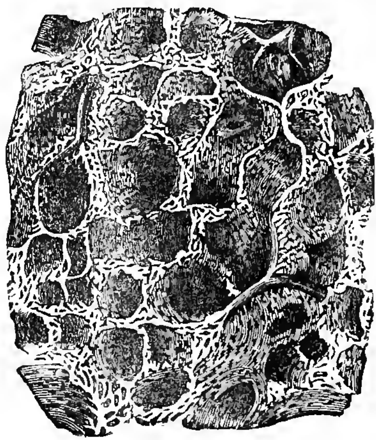


FIG. 81.—Alveoli of the lungs, showing blood-vessels. (Magnified.)

lines the walls of the chest. The serous cavity between the two layers of the pleura contains pleural fluid which the internal surface secretes, and which lubricates their surfaces. The lungs are pink in colour, light, spongy, and elastic. They nearly fill the cavity of the thorax, and are kept on the stretch by the pressure of the air which acts down the windpipe.

DISSECTION OF SHEEP'S LUNGS

Experiment 49.—(1) Obtain from a butcher the lungs and heart of a sheep. Carefully examine them, and note (i) The lungs are smooth, and pink in colour. The smooth feel is due to the visceral layer of the pleura. (ii) They are soft and spongy. Remove a small piece from one lung and place on a basin of water. It floats. (iii) Find the windpipe, and its opening, the **glottis**. In front of the glottis stands the **epiglottis**. (iv) The left lung is divided into two lobes, and the right into three lobes. Make a sketch of the lungs and windpipe.

(2) Insert into one of the divisions of the trachea an enemic syringe, and pump air into it. The lung expands, becomes pale in colour, and, if sufficient force is used, the visceral layer of the pleura may be blown away. Withdraw the syringe quickly, the lung shrinks, and returns to its original condition. In the perfect chest the lungs are always kept on the stretch, and this is due to the pressure of the air acting down the windpipe. This experiment also shows that the lungs are elastic and can be stretched, but contract when the pressure is removed.

(3) Examine the windpipe. Note (i) the position of the larynx, and that it is a cartilaginous box formed of rings of cartilage. The opening into the larynx is the glottis, to which is fixed the epiglottis. (ii) The portion of the windpipe below the larynx is the trachea. Cut a few rings from the trachea, and note that each ring is incomplete behind, the ends being embedded in muscle. The rings are joined with connective tissue. Open the trachea, and note the smooth interior, which is lined with mucous membrane, to which mucus may cling. Note where the trachea branches

to form the bronchi. (iii) With a knife scrape away from the right lung the soft lung substance, the bronchus and bronchial tubes will be exposed to view. Follow one bronchial tube to where very small branches are formed which have no cartilages in their walls. (iv) Cut across the left lung, and find on the surface the ends of the bronchial tubes which have cartilages in their wall. The arteries are circular in shape, open and white in colour. The veins are blue, closed, and thin-walled. Between these structures the soft lung substance will be seen. (v) Find the pulmonary artery, which arises at the base and front of the heart (p. 88). Follow it until it divides, and trace out the right branch to the point where it enters the right lung. Make out the pulmonary veins which enter the left auricle, and follow them upwards into the lungs. Find the factors of the pulmonary veins; they are smaller vessels which join to form the main trunk. (vi) Pick up with a pair of forceps the thin visceral layer of the pleura and strip off a small piece. Note its characters.

Experiment 50.—Examine under the low power of the microscope a prepared section of the lung. Note (1) the bronchial tubes; (2) blood-vessels; (3) the alveoli or air-cells (p. 195). These appear large, thin-walled, and irregular in shape.

QUESTIONS FOR REVISION

1. What do you understand by respiration?
2. Describe the general structure of the nose, dwelling especially upon the structure and uses of the respiratory mucous membrane.
3. In ordinary breathing the air should always pass through the nose. Explain why.
4. What is the pharynx? Where is it found, and what structures open into it?

5. Describe in simple language the structure of the windpipe and its use.

6. What is an infundibulum? What vessels run in the walls of an infundibulum?

7. Describe the structure of an alveolus.

8. Give an account of the structure of the human lungs.

9. What is the most important property of the lungs while in the living body?

10. If a lung is cut across, what structures can be seen?

CHAPTER XVII

THE WALLS OF THE THORAX AND RESPIRATION

THE WALLS OF THE THORAX.—The floor of the thorax is formed by the diaphragm, the roof by the roots of the neck, the front by the sternum, costal cartilages, and intercostal muscle, the back by the thoracic vertebræ, and the sides by the ribs and intercostal muscles. The front, sides, and floor are movable.

THE DIAPHRAGM.—The centre of the diaphragm is composed of tendinous material, which is surrounded with striated muscle (Fig. 82). It is connected to the sternum in front, the floating ribs at the sides, and the pillars of the diaphragm behind. The muscular portion contracts and pulls down the tendinous portion, which makes the chest larger from above to below. The descent of the diaphragm displaces the stomach and the liver, and these push outwards the muscles of the abdomen. When the muscular portion of the diaphragm relaxes, it is pushed back to its original position by the abdominal muscles pressing on the stomach and liver. The diaphragm is concave to the abdomen and convex to the thorax. The descending aorta, inferior vena cava, œsophagus, and thoracic duct pass through the diaphragm. It is also used, in addition to breathing, for other purposes, such as assisting in emptying the bowels.

THE RIBS AND INTERCOSTAL MUSCLES.—Each rib is a curved bone which articulates by two processes with a thoracic vertebra, and can move in an upward and downward direction. The spaces between

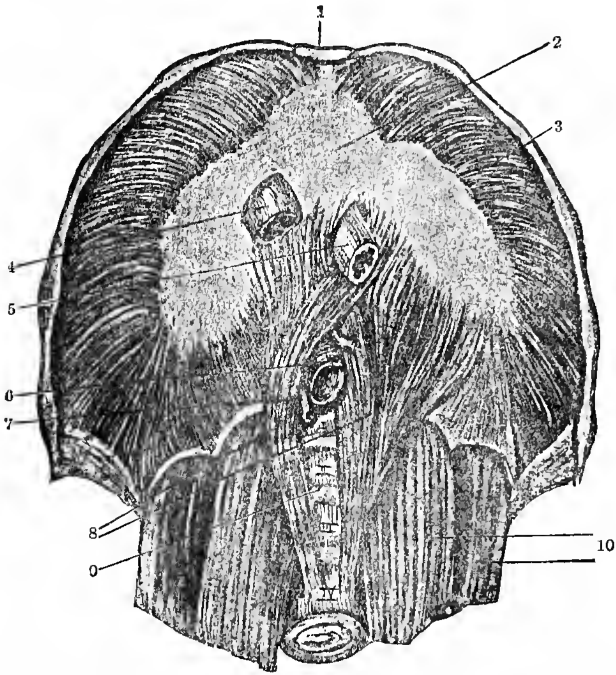


FIG. 82.—The diaphragm as seen from below. 1, end of sternum; 2, tendinous portion of diaphragm; 3, muscular portion of diaphragm; 4, inferior vena cava; 5, œsophagus; 6, aorta; 7, thoracic duct; 8, muscles of diaphragm; 9, lumbar vertebræ; 10, muscles of abdomen.

the ribs contain intercostal muscles, which are divided into two sets, the external and internal. The former as a general rule run from above, slanting forward to the point where they join the lower rib. The external intercostals, when they contract, pull the rib

and sternum upwards and outwards. This makes the chest wider from front to back and from side to side. When the external intercostal muscles relax, the sternum and ribs move back to their original position. This may be aided by the contraction of some of the internal intercostals. Thus the size of the chest can be altered by the action of the muscles of the diaphragm and the ribs. In ordinary quiet breathing these are the only muscles brought into action, but in extraordinary breathing other muscles are called into play. The muscles of the diaphragm and ribs are under the control of the will, but only to a limited extent.

Experiment 51.—Place your hand on the front of your chest, and count the number of times it rises per minute (1) when at rest, (2) after exercise. The walls of the chest rise and fall once for each respiration. The nervous system has such an important action in governing respiration that, if the student should get excited, the numbers obtained may be abnormal. In such a case, try again.

Experiment 52.—Remove from a dead rabbit the diaphragm, and spread it out on a post-card. Carefully examine, and note (*a*) the central tendinous portion, (*b*) the outer muscular portion.

Experiment 53.—From a dead rabbit cut out a pair of ribs with their intercostal muscles. Now with care dissect away the outer or external intercostal muscles, noting how they are fixed to the ribs, and the direction of slope. In a similar way examine the internal intercostal muscles. Make a sketch illustrating your observations.

Experiment 54.—With laths, tacks, and elastic bands

construct a model to show the action of the intercostal muscles during respiration. Cut from a lath four pieces, one about 6 inches, another 5 inches, and two 4 inches. Fasten them together by means of a bradawl and brass tacks, as shown in Fig. 83. Now place tacks for the elastic bands.

Parts in the Model.—AB, a fixed bar to represent the back-bone; CD, a movable bar to represent the

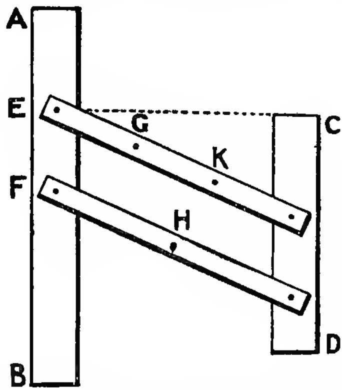


FIG. 83.—Model to show action of intercostal muscles during respiration. For explanation see text.

sternum; E and F, two bars to act as ribs; G and H, tacks for the elastic band, which represents the external intercostal muscles, and K and H represent the internal intercostal muscles.

Working of the Model.—The elastic band which stretches from G to H, in shortening, pulls up the rod CD. The external intercostal muscles, when they contract, pull the ribs and sternum upwards and outwards, and this makes the chest wider from back to front. The elastic band is now moved to K and H, and in

shortening it pulls down the rod CD. The depression of the ribs and sternum is largely a question of elastic recoil, but the internal intercostal muscles may aid in depressing the ribs and sternum.

Experiment 55.—Obtain a bell-jar or large lamp-glass, a cork which will fit the top of the jar or glass, a glass tube, toy bladder, and a piece of tightly-woven cloth or sheet of elastic. Make a hole in the cork, insert the glass tube, and tie over the other end of the tube the toy bladder or the fresh lung of a rabbit. Fit the cork in position so that the bladder is inside the jar (Fig. 84). The sheet of elastic or cloth is placed on the bottom of the bell-jar. Now pull the cloth downwards—the bladder or lungs expand. Push the cloth upwards—the bladder shrinks. Pull the cloth up and down in a regular manner, the air enters and leaves the bladder at regular intervals.

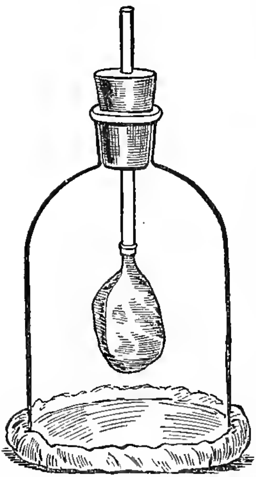


FIG. 84.—Apparatus to show action of diaphragm during respiration.

Working of the Model.—The bell-jar represents the air-tight walls of the chest, the cloth the diaphragm, the glass tube the trachea, and the toy bladder the lungs. When the space above the cloth is made larger by pulling it down, the bladder follows the enlargement because the pressure is less inside the glass than outside. It is the difference in pressure which fills and empties the bladder. The lungs act in a similar manner.

When the radiating muscle of the diaphragm and the external intercostal muscles contract they make the chest both deeper and wider, and the lungs follow this enlargement due to the pressure of the air down the trachea. When the muscles relax, the ribs and sternum fall downwards, and the diaphragm is pushed back by the action of the abdominal muscles and organs which were displaced by its movement. This forces the air out of the lungs, because the pressure is greater inside than outside.

RESPIRATION.—When the chest is made larger by the movements of the diaphragm and ribs, the pressure inside the lungs falls for an instant below that of the external atmosphere. The average pressure of the air equals 15 pounds per square inch, and it is always pressing with this amount on each square inch of the surface of the body. The difference between the pressure inside the lungs and the external air produces a movement of air into the lungs, which brings about equal pressure; this is known as an **inspiration**. When the muscles which produce the enlargement of the chest relax, the chest returns to its original size, and the pressure inside the lungs becomes greater than that of the external air. This causes the air to leave the lungs to bring about equal pressure. This is known as **expiration**. It is thus the differences in pressure between the air inside the lungs and the external air which bring about inspiration and expiration. From this it will be seen that each respiration consists of an inspiration and an expiration.

AIR IN THE LUNGS.—The air which enters the lungs during inspiration is called tidal air, and it amounts to between 20 and 30 cubic inches. If a

500 cc

very deep breath is taken, 100 cubic inches more may be taken in, and this is called **complemental** air. The lungs usually contain 100 cubic inches of **residual** air, *i.e.* air which cannot be driven out by the strongest expiration. In adition to the residual air, the lungs also contain 100 cubic inches of **supplemental** air, which

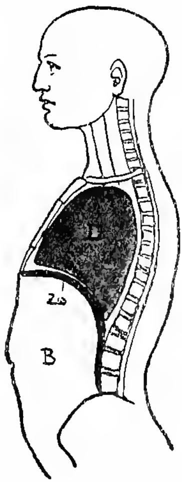


FIG. 85.—Diagram showing the position of the diaphragm and the muscles of abdomen when breathing in (inspiration). *L.* lung; *Zw*, diaphragm; *B*, cavity of abdomen.

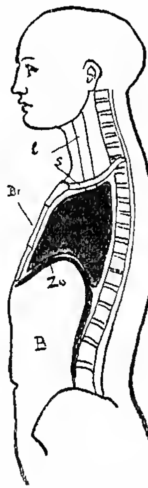


FIG. 86.—Diagram showing the position of the diaphragm and muscles of abdomen when breathing out (expiration). *t.* trachea; *L.* lung; *S*, clavicle; *Br*, sternum; *Zw*, diaphragm; *B*, cavity of abdomen.

can be driven out by a strong expiration. The residual and supplemental air is known as **stationary** air, because during life it remains in the lungs. Thus the lungs, when fully expanded, may contain as much as 330 cubic inches of air, but never less than 100 cubic inches.

The tidal or inspired air gives oxygen up to the stationary air, and receives carbon dioxide in exchange.

This is brought about by diffusion, the stationary air and tidal air coming into contact with each other, and the interchange goes on at all the points where they touch. It receives aqueous vapour during its journey through the air passages, and its temperature becomes equal to that of the body. It also gains a little organic matter during the time it remains in the lungs and air-passage.

CHANGES IN AIR DURING RESPIRATION.—The following table illustrates the changes which the tidal air undergoes during its stay in the lungs and air-passages, and Experiment 56 explains how the changes can be roughly demonstrated.

	Nitrogen.	Oxygen.	Carbon Dioxide.	Aqueous Vapour.	Temperature.	Organic Matters.
Inspired air	79·00	20·96	0·04	Varies.	Varies.	No traces.
Expired air	79·00	16·00	4·00	Saturated.	98·4° F.	Traces.

Experiment 56.—(1) Place a little lime-water in a test-tube, and by means of a glass tube blow or breathe air through it. The lime-water turns milky. This is a test for carbon dioxide.

(2) Look at a mirror or slate. It is bright and clean. Now breathe on it, and note the film of moisture which is deposited.

(3) Place a little weak Condy's fluid (potassium or sodium permanganate) or sulphuric acid in a test-tube, and by means of a long glass tube blow or breathe through it. The fluid or acid changes colour. This shows that organic matters leave the body with the expired air.

(4) Breathe on the bulb of a thermometer for some time, and note that it registers a higher temperature

It should register 98·4° F., or nearly 37° C., but in practice this is not reached.

(5) Set and wash a clinical thermometer, and place it beneath the tongue for a short time. It registers 37° C. or 98·4° F.

From the above experiments we learn that expired air contains more carbon dioxide, aqueous vapour, and organic matters than the inspired air, and that its temperature is generally raised during respiration.

CHANGES PRODUCED IN THE BLOOD DURING RESPIRATION.—The blood which the pulmonary artery and its branches bring to the capillaries of the lungs is venous, but the blood in the pulmonary veins is arterial. The blood in the capillaries is separated from the air in the alveoli by the thickness of the wall of the capillary and alveoli. The oxygen in the air passes through the thin wall into the blood, where the hæmoglobin unites with it to form oxyhæmoglobin (p. 79). The carbon dioxide passes from the blood in the reverse direction into the air in the alveoli. This process changes the venous into arterial blood.

Experiment 57.—(1) Obtain some fresh whipped blood from a butcher, and note the bright scarlet colour. This is due to the mixing of air with the blood, the hæmoglobin being changed to oxyhæmoglobin.

(2) Place some blood in a test-tube, and add a little ammonium sulphide solution to it. This re-agent acts on the oxyhæmoglobin and sets the oxygen at liberty, and the blood becomes reddish purple, which is the usual colour of hæmoglobin.

(3) Fix to the gas-pipe an india-rubber tube, and allow some coal gas to bubble through some of the whipped blood. It turns of a cherry-red colour. This is due to the carbon monoxide (carbonic oxide) in

the coal gas uniting with the hæmoglobin to form carbon monoxide hæmoglobin. This is a staple compound, and cannot carry oxygen.

THE NERVOUS SYSTEM AND RESPIRATION.—The movements of respiration are produced by and are under the control of the respiratory centre, which is situated in the spinal bulb, near the origin of the vagus nerves. This centre sends impulses down the spinal cord to the intercostal muscles, and along the phrenic nerves to the diaphragm. The respiratory centre is influenced by impulses which reach it along the fibres of the vagus nerves, which are connected with the lung substance, by impulses from the higher centres of the brain, and the skin. Inspiration is caused by impulses which pass from the centre along the phrenic nerves to the muscles of the diaphragm, and intercostal nerves to the external intercostal muscles. These by their contraction increase the size of the thorax, thus leading to the entrance of air. Expiration is largely due to elastic recoil, but it is aided by nervous impulses which pass to the internal intercostals, and which help to move the ribs to their old position.

APNŒA, DYSPNŒA, AND ASPHYXIA.—After exercise, as in mountain-climbing, the movements of respiration become much slower, which may be due to the blood being loaded with oxygen, and to the decrease in the quantity of carbon dioxide present. This condition is known as **apnœa.** If breathing is obstructed by the closing of the windpipe, by impure air or after-damp, the respiratory movements increase in number and become deeper. This condition is known as laboured breathing or **dyspnœa.** If the condition which has caused dyspnœa is not removed, the expiratory

movements are increased, but the inspiratory ones decrease in strength, and **asphxyia** is produced. The blood throughout the body is venous after death from asphyxia.

MODIFIED RESPIRATIONS

The movements of respiration may be modified so as to produce sighing, coughing, sneezing, sobbing, snoring, hiccough.

Sighing.—A deep, long inspiration produces the sound known as sighing.

Coughing.—A deep inspiration followed by a violent expiration with the glottis closed causes coughing.

Sneezing.—This is the same as coughing, but the mouth is closed and the air is forced through the nose.

Sobbing.—In sobbing there are a series of inspirations, the air coming in contact with a partially-closed glottis.

Snoring.—In snoring the air sets the soft palate vibrating, and this gives rise to the well-known sounds.

Hiccough.—The muscular portion of the diaphragm suddenly contracts and produces inspiration. The entering air comes in contact with the closing glottis, thus producing the well-known sound.

Yawning.—This is due to the blood not receiving enough oxygen, and nature's method is to produce deep inspiration with movements of the jaws, &c.

QUESTIONS FOR REVISION

1. What structures form the walls of the thorax or chest, and how is the thorax made air-tight?
2. How is the diaphragm placed in the body? Of what two kinds of tissue is it chiefly made up, and how do these act in carrying on the work of breathing?
3. How can you demonstrate, by simple apparatus, the action of (*a*) the intercostal muscles; (*b*) the diaphragm in producing inspiration and expiration?

4. Describe the form, position, and attachments of the sternum. What changes of position does it undergo in breathing?

5. Describe a set of experiments which illustrate the difference between the inspired and expired air.

6. What is the essential difference between the blood in the right and left sides of the heart? Explain where the blood comes from which reaches each side of the heart, and what has caused the difference between the two kinds of blood?

7. How does the nervous system govern the movements of respiration?

8. Define *apnœa.* How is apnœa produced?

9. Explain what is meant by dyspnœa and asphyxia, and how these are brought about.

10. Enumerate and explain a few modified respiratory movements.

CHAPTER XVIII

THE SKIN AND ITS FUNCTIONS

THE skin consists of an outer portion, which is known as the **epidermis**, and a deeper one, the **dermis**. The skin is sensitive, and this important function helps to protect the enclosed structures from injury. At the mouth, nose, and anus the skin joins the mucous membranes, which line these organs. The epidermis is much thicker on the palms of the hands and soles of the feet; this is due to the greater use of these parts. Corns are generally due to the pressure of shoes or boots on the skin.

THE EPIDERMIS.—The epidermis consists of a soft **Malpighian** layer of cells, which is in contact with the dermis, and which contains pigment. Its cells are tall and columnar in shape, and they undergo division, the older cells being pushed upwards to form the outer **horny** or **corneous** layer. The corneous layer is built up of numerous layers of cells which are stratified; the deeper ones consist of fairly tall cells, but if they are traced upwards they decrease in size, and near the surface become mere scales. From the surface of all parts of the epidermis the scales are shed; this process brings new scales to the surface, so that new skin is constantly being formed. Through the epidermis runs the ducts of the sweat gland, and the hair-follicles and hairs belong to this part of the skin. There are no blood-vessels in the epidermis, and the **Malpighian**

layer is nourished by lymph, but a few nerve fibres end between its cells.

THE DERMIS.—The dermis is thrown into little elevations, which receive the name of papillæ, the spaces between being filled up with the Malpighian layer of the epidermis. It is made up of a dense

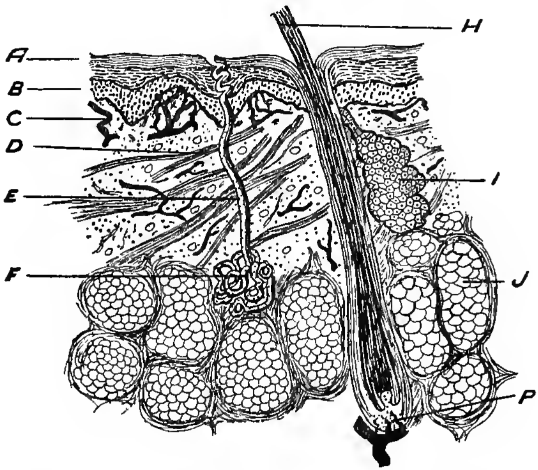


FIG. 87.—A section of human skin (partly diagrammatic). *A*, horny or corneous layer of epidermis; *B*, Malpighian layer of epidermis; *C*, capillaries; *D*, muscle fibres; *E*, duct of sweat gland; *F*, body of sweat gland; *H*, hair; *P*, papilla at base of hair-follicle; *I*, sebaceous gland; *J*, adipose tissue.

mass of fibrous tissue, which contains numerous blood-vessels, nerves, sweat glands, sebaceous glands, and adipose tissue. The blood-vessels form loops round the bodies of the sweat glands and papillæ at the base of the hair-follicles. Thus the dermis differs from the epidermis in containing blood-vessels. The nerves enter the different structures which are sensitive to

the touch, and the number of touch organs which are present in any part of the dermis govern its sensitiveness; for the more numerous they are, the greater its power of distinguishing objects which it comes in contact with.

THE SWEAT GLANDS.—Each sweat gland is made up of a long tube, which is coiled up to form a body or secreting portion; this is lined with tall cells, which suitable stains define; a long conducting tube or duct passes through the dermis, and runs in a zigzag manner, finally opening on the surface. The sweat glands are very abundant on the palms of the hands and soles of the feet. Their function is to produce sweat.

SWEAT.—The sweat, which is separated from the blood by the action of the sweat glands, is a fluid which consists of water, salts, and carbon dioxide. On an average two pounds of sweat is produced each day, and in most cases it leaves the skin so slowly that it is not perceived, when it is known as **insensible perspiration.** In hot weather and during hard muscular work the sweat passes from the ducts of the sweat glands so quickly that it stands on the surface of the skin, when it is known as **sensible perspiration.** The sweat contains on an average the substances enumerated below:—

Water	99·00	per cent.
Common salt	0·25	,,
Other salts	0·15	,,
Fats	0·40	,,
Epithelium	0·20	,,

Some of the fatty matters in the sweat comes from the sebaceous glands, and this is the principal cause

of its acid reaction; however, during the production of sensible perspiration it is alkaline.

THE SECRETION OF SWEAT.—The secretion or excretion of sweat is under the control of the nervous system, and the vaso-motor nerves, which govern the size of the small arteries in the skin, help to regulate the amount produced. If the size of the arteries is diminished, less sweat is produced, but on dilation the increased supply of blood to the sweat glands leads to an increase in the amount. In addition there are special nerve fibres and sweat-centres which control sweating; the latter may be influenced by (1) venous blood circulating in them; (2) the action of drugs, such as nicotine and camphor. During laboured breathing and asphyxia the venous blood, acting on the sweat-centres, produces profuse sweating. If large quantities of water and other beverages are taken into the body the blood pressure is raised, and this increases the quantity of sweat produced. A dry or heated atmosphere is favourable to sweating.

Experiment 58.—(1) Examine the skin of your own arm, and note if it is firm and elastic, yet loose enough to be easily moved. In an unhealthy person the skin may be soft and flabby and very loose, thus contrasting very unfavourably with that of a perfectly healthy individual.

(2) Find the hairs which grow from the upper surface of the arm and back of hand, noting that they point in certain directions. The direction in which the hairs point and their state of development varies in different parts of the body.

(3) Find, with the help of a hand-lens, the ridges which exist in the palm of the hand, and on these the small openings of the ducts of the sweat glands.

(4) The skin of the palm is much harder than that on the back of the hand; this is principally due to the greater use made of the former, which favours its growth and development.

(5) Carefully examine a nail on one of your fingers, and note its shape, colour, and general appearance. The nails, like hairs, belong to the epidermis, and do not contain blood-vessels. This can be proved by cutting a nail or hair, when no loss of blood follows.

Experiment 59.—(1) Obtain a clean blunt knife and scrape the back of the hand, and mount the scrapings in a drop of salt solution. Examine with the microscope, and note the shape and appearance of the numerous scales in the field of view.

(2) Stain a similar preparation, or, better still, mount the scrapings in a drop of eosin, and examine.

(3) Remove a very thin layer of skin from the lower lip, and spread out in a drop of salt solution. Examine, and note the numerous cells which are united to form a membrane.

Experiment 60.—(1) Obtain a prepared vertical section of the human skin, and examine with a microscope. Note (i) the outer or epidermal layer is made up of closely-packed cells, which change their shape towards the surface, where they become mere scales. (ii) The deeper or dermal layer, which consists of dense fibrous tissue and contains numerous structures. (iii) The sweat gland, with its coiled-up body, which lies deep in the dermis, and the long duct or conducting tube, which slightly bends from side to side in the dermis, but is spirally arranged in the epidermis. (iv) The hair-follicle, which is deeply embedded in the dermis, but which is surrounded by

a layer of the Malpighian layer of the epidermis. At the base of the follicle there is a papilla of the dermis which is well supplied with blood-vessels. (v) The masses of adipose tissue which gives rotundity to the figure. (vi) Try and make out the distribution of

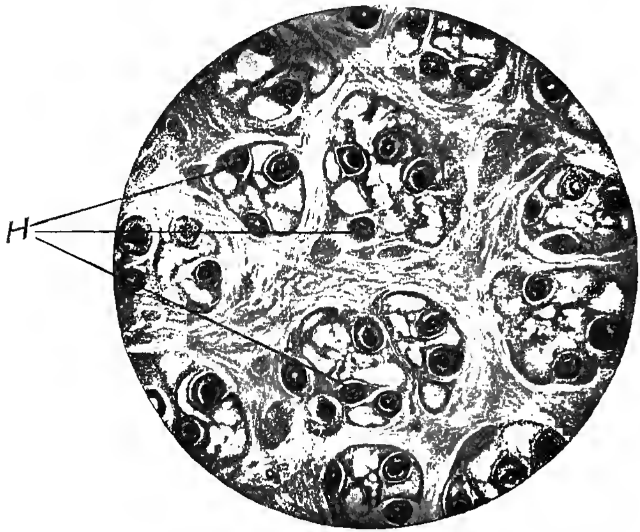


FIG. 88.—Horizontal section of human scalp. *H*, hair and hair-follicles seen in transverse section. (Photomicrograph by Flatters, Milborne & M'Kechnie.)

the blood-vessels which form loops round the bodies of the sweat glands (Fig. 87). Sketch.

(2) If possible, obtain a cross section of the scalp, and find (i) the masses of adipose tissue; (ii) the hair-follicles with their sheaths; (iii) the cut ends of the ducts of sweat glands (Fig. 88). Sketch.

Experiment 61.—(1) Remove from your own hand a few hairs, and soak them in methylated spirits for a

few minutes to remove the air. Mount in salt solution and examine. Note (i) the cortex or outer portion of the hair; (ii) the medulla or inner portion of hair. Sketch.

(2) Fasten a single hair to a slide with some hot sealing-wax, and treat with strong caustic solution for fifteen minutes. Examine and note the cuticle, which surrounds the cortex, and consists of a single layer of cells.

THE FORMATION AND STRUCTURE OF HAIRS.—Early in the life of the embryo small elevations or papillæ appear on the surface of the skin; at a later period these sink downwards, carrying with them the epidermis forming the primary hair-follicles. Each hair-follicle consists of an outer **root-sheath**, which belongs to the epidermis, and an inner **dermic layer**, which belongs to the dermis. The root-sheath can be divided into an outer portion, which is continuous with the Malpighian layer, and an inner one, which joins the corneous layer. The former is known as the outer root-sheath, and the latter forms the inner root-sheath. A membrane separates the root-sheath from the dermic layer, which surrounds the root of the hair-follicle. The root is much larger than the rest of the follicle, and there projects into its base a dermic papilla which is well supplied with blood-vessels. The growth and division of the cells which fit over the dermic papilla push off the older portion which forms the hair; thus the growth of the hair takes place in the base of the hair-follicle. In time the hair-follicle grows old and may fall out, but it generally leaves a bud behind, which forms a new one. It is impossible to produce hairs on any portion of the body from which hair-follicles are absent, and the application of hair-restorers

under these conditions can do no good. The hair-follicle is connected with muscles, and the contraction of these cause the erection of the hair. In cold weather and during fear the action of the muscles is brought into play, and the hairs stand straight up. A pair of sebaceous glands are connected to each hair-follicle; these are racemose structures which secrete sebum, which lubricates the hairs and surface of the skin, and their ducts open into the hair-follicle.

Each hair is made up of a medulla or inner portion, and an outer pigmented cortex, which is covered with a layer of cells which form a cuticle (Experiment 60). The colour of the hair depends upon the colour of the pigment which the hair contains, and the loss of this, as in old age, is the cause of grey hair.

NAILS.—Nails are formed from the corneous layer of the epidermis, and, like hairs, do not contain any blood-vessels. Each one is formed in a deep depression or fold of the skin, which is known as its bed, and the cells in the deeper layer of the epidermis divide and grow with great rapidity; these are pushed off to form the nail. The dermis at the base of the nail-bed is thrown into ridges, and these are very vascular and sensitive, the lymph formed from the blood in the dermis nourishing the deeper layer of the epidermis.

THE FUNCTIONS OF THE SKIN

Numerous functions are performed by the skin; these are:—

(1) **It aids in the regulation of the temperature of the Body.**—The normal temperature of the body is 98·4° F. (37° C.), and during health the variation of this lies between 98° and 99° F. The sweat is

evaporated from the surface of the skin by the heat of the body, and during profuse sweating a considerable quantity of heat will be used. During warm weather and muscular exercise the vaso-motor centre sends less impulses along the vaso-motor nerves, and the small arteries in the skin dilate, thus increasing the supply of blood to the sweat glands, which produces more sweat; this is passed to the surface of the skin, where it is evaporated by the excess of heat, and this keeps the temperature at the normal. In addition there is a centre (thermogenetic) in the brain whose function is to regulate the amount of heat produced in the body, and the combined action of the vaso-motor and thermogenetic centres regulate the temperature of the body. Cold-blooded animals have no means of regulating their temperature, and it varies with the changes in the medium in which they live, but all warm-blooded animals possess centres which keep the temperature fairly constant under nearly all conditions of climate.

(2) **It is an Organ of Secretion.**—The sebaceous glands, which are connected with the hair-follicles, secrete a fatty substance, which is known as sebum, and this lubricates the skin and hair. In the absence of this secretion the skin and hair becomes dry and scaly. Sebum may accumulate to such an extent in the glands that small pimples are formed; these should be squeezed out, and the places sponged with a little weak methylated spirits.

(3) **It protects the deeper Organs from Injury.**—The skin is well supplied with nervous structures, and these by their sensitiveness prevent injury to the organs beneath. It is common knowledge how difficult it is to push a needle into the finger, and it can only be done by accident or with great quickness. This is

owing to the pain which arises from the needle coming in contact with the touch organs in the papillæ in the dermis. Dirt and organisms cannot enter through the skin to any great extent unless the epidermis is injured. Substances can be forced into the skin by friction, and in this way fatty materials along with drugs may enter the deeper structures.

(4) **It is an Organ of Respiration.** — It has been ascertained by careful measurement that a little oxygen enters, and that carbon dioxide is expired through the skin. The quantity lost in this way does not exceed the $\frac{1}{150}$ of that lost through the lungs.

ATTENTION TO THE SKIN.—The beauty of the body depends very largely on the skin being kept in good condition, and, in addition, health can only be maintained when it readily responds to stimulation. Dirt on the skin not only looks bad, but is injurious to health and offensive to others. Good soap, such as Ivy or Pears' soap, should be used along with plenty of water, and these along with friction will remove any dirt which may accumulate on the skin. A hot bath should be used each week, and a cold one each morning. Exercise of every description helps to give tone to the skin ; walking, swimming, cycling, running, football, cricket, and golf can be heartily recommended.

The nails should be cut short, and well brushed to remove dirt, for dirty nails often carry disease germs. The hair should be kept clean and neat, and when necessary the ends should be cut.

QUESTIONS FOR REVISION

1. What are the two chief parts of the skin, and how do they differ from each other? How does the skin of the heel differ from that of the under lip?

2. What is sweat, and how is it secreted?

3. Describe the structure of a hair. On what parts of the body are hairs produced, and how?

4. What is sebum? How is it produced, and of what service is it?

5. Enumerate the functions of the skin.

6. After violent exercise a man says "he is very hot." Is he really hotter than usual? If not, why not?

7. Give a set of rules which should guide one in attending to the skin.

8. What is a sweat gland? In what part of the skin are the sweat glands most numerous?

9. What is perspiration, and how is it produced? What is meant by *sensible* and *insensible* perspiration?

CHAPTER XIX

THE KIDNEYS AND BLADDER

THE KIDNEYS.—The kidneys are reddish-brown organs which lie one on either side of the vertebral column in the lumbar region of the abdomen. The left kidney is nearer the diaphragm than the right, which is slightly displaced downwards by the liver. Each kidney is kidney-bean shaped, and its concave border faces the vertebral column. The blood-vessels both enter and leave the kidney on the concave side, and there also arises near them a fairly large tube, the **ureter**, which conducts the urine from the kidney to the bladder. The peritoneum covers the front of the kidney, which is generally embedded in fat, and on its upper surface rests a suprarenal capsule which is shaped like a cocked-hat. The kidney is 4 inches long, $2\frac{1}{2}$ wide, and about 1 inch in thickness.

THE STRUCTURE OF THE KIDNEY.—A very thin capsule covers the kidney, and this can be easily removed by means of a pair of forceps. If the kidney is divided lengthwise with a knife, a dark outer portion will be seen, the **cortex**, and a light-coloured inner portion, the **medulla.** The medulla consists of a dozen or more **pyramids**; each pyramid is conical in shape, and made up of nearly a thousand tubules, the **tubuli urinifera.** The apex of the pyramid points towards the concave border. If the ureter is traced into the hilus of the kidney, it is seen to increase in

size, and forms a **pelvis**; this divides to form little cup-shaped **calyces**, and into each one the apex of a pyramid projects.

Each tubuli urinifera or urine tubule commences in the cortex as a dilated body, which forms a **Mal-**

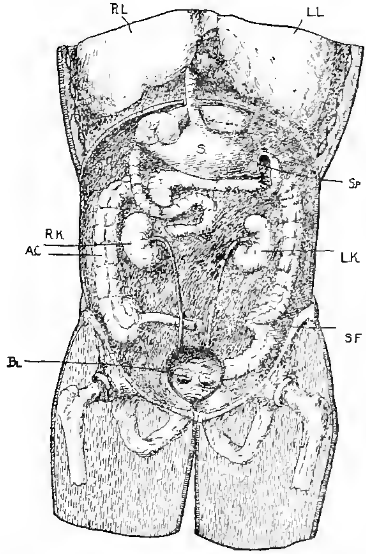


FIG. 89.—Diagram showing position of kidneys and bladder. *R.K.* right kidney; *L.K.* left kidney; *Bl.* bladder; *A.C.* ascending colon; *Sp.* spleen; *S.* stomach; *R.L.* right lung resting on diaphragm; *L.L.* left lung resting on diaphragm; *S.F.* sacculate folds of descending colon. Note the pancreas with its head up to the duodenum.

pighian capsule, and ends at the apex of the pyramid. Each tubuli urinifera or urine tubule consists of:—

(1) A dilated portion which is known as a **Malpighian capsule**, which is lined with flat cells, and contains a ball of capillaries, which is known as a **glomerule.**

(2) A **first convoluted** portion, which is lined with

tall granular cells, and remains in the cortex. It is surrounded by a number of capillaries.

(3) A loop of Henley, which enters the medulla, and is lined with flattened cells.

(4) A **second convoluted** portion high up in the cortex, which contains granular cells. It is surrounded by capillaries.

(5) A collecting portion which contains flattened cells and joins on to similar tubules, which end at the apex of a pyramid.

THE BLOOD SUPPLY OF THE KIDNEY.—From the aorta there arises a branch artery which ends in the kidney, and which is known as the **renal artery.** The renal artery branches in the hilus, and these pass between the pyramids to the junction of the cortex and medulla, where they turn over to form arches. From the arches small arteries arise which enter the cortex, where they branch; the smaller branches enter the Malpighian capsules to form the glomeruli, or supply the capillaries on the outside of the convoluted portions of tubules. A small vein collects the blood from the glomerulus inside the Malpighian capsule, and this joins the capillaries, which surround the convoluted portions of the tubule. Small veins bring the blood from the second set of capillaries, and these enter venous arches at the junction of cortex and medulla. From the venous arches veins run between the pyramids, and empty into the **renal vein**, which enters the inferior vena cava.

DISSECTION OF THE KIDNEY

Experiment 62.—Obtain from a butcher a fresh sheep's kidney which is covered with fat, and proceed to discover its structure.

(1) Remove the fat without injuring the kidney, and find resting on its anterior surface the supra-renal capsule. Note its shape and appearance.

(2) Find the ureter and blood-vessels. Examine (i) the ureter, the thickness of its walls, and how it enters the hilus of the kidney; (ii) the renal artery, noting its open end and thick walls; (iii) the renal vein, which is thin-walled and closed; (iv) strip off the capsule, which is loosely fastened to the kidney.

(3) Open the ureter with a pair of scissors, and note how it expands in the kidney to form the pelvis. Note the lining of the ureter, and that the pelvis divides to form a number of cup-shaped calyces, each of which surrounds the apex of a pyramid.

(4) Divide the kidney with a sharp knife length-wise, and note the dark cortex and light-coloured medulla. Examine a pyramid, and note its striated appearance, which is due to the numerous collecting tubules.

(5) Follow the renal artery into the kidney, and its branches which pass in between the pyramids.

Experiment 63.—(1) Remove one of the pyramids from the kidney used in the previous experiment, and try and unravel it so as to expose the tubules.

(2) Tease out a little of the pyramid in salt solution, and find the parts described on p. 224.

(3) If possible, examine a prepared section of the human kidney, and trace out the structure of a Malpighian capsule, convoluted portion of tubule, &c.

THE URETERS.—The ureter is the duct of the kidney, and is of the size of a quill-pen. It consists of:—

(1) An internal coat of several layers of cells which

rest on a basement membrane of some thickness, and forms a mucous membrane.

(2) A middle muscular coat which consists of plain muscle, and the contraction of which helps to force the urine into the bladder.

(3) An external coat of fibrous tissue.

The ureter enters the bladder in an oblique manner, and runs for a distance in its walls, thus forming a kind of valve which prevents the backward flow of urine.

THE BLADDER.—The bladder is a pyriform body in which the urine secreted by the kidneys is stored up, and it is protected from injury by the bony walls of the pelvic basin in which it is placed. It is made up of:—

(1) An internal coat of mucous membrane of the usual kind.

(2) A submucous coat of connective tissue, which is slightly elastic.

(3) A middle coat of plain muscle, which is arranged in two layers, one circular, the other longitudinal.

(4) An external serous coat formed from the peritoneum.

The bladder opens into the **urethra**, which is lined with mucous membrane. A circular or sphincter muscle, which is under the control of the will, guards the opening of the bladder. The bladder is well supplied with blood-vessels, lymphatics, and nerves.

Experiment 64.—(1) Obtain from a butcher the bladder of a sheep, and note its shape and general appearance. Pass a piece of string around the opening so as to close it. Warm the bladder, and note how it expands. Allow it to cool; it returns to its former

size. This experiment illustrates the fact that the bladder can change its size.

(2) Dissect the bladder, and discover the three coats, noting the sphincter muscles at the end of the urethra.

THE URINE.—Healthy urine is a clear yellowish fluid which contains organic and inorganic salts, colouring matters, and gases. It generally gives an acid reaction, and has a specific gravity of about 1·020. The quantity of urine which leaves the kidneys is about 50 ounces per day, but the amount varies with the quantity of liquid drank and the condition of the atmosphere. The daily urine contains about 2½ ounces of solids, and these are given below—

Organic salts { Urea, Uric acid, Hippuric acid.

Inorganic salts { Sodium chloride, Sodium sulphate, Sodium phosphate.

Colouring matters.

Gases { Such as carbon dioxide, Nitrogen, Oxygen.

Experiment 65.—(1) Collect the urine passed during twenty-four hours, and with a hydrometer take its specific gravity, which should vary between 1·015 and 1·025.

(2) Test the reaction of the urine with litmus paper. Is it acid or alkaline?

(3) Place a little urine in an evaporating dish, and evaporate to dryness. Note the residue, which consists of urea, uric acid, and inorganic salts.

(4) Carefully evaporate a little urine so as to reduce to one-quarter of the quantity. Add to it a few drops

of nitric acid, and mount a drop on a slide, cover, and examine for crystals of nitrate of urea.

(5) Place a few crystals of urea in a test-tube, and warm; a smell of ammonia will be perceived. This shows that urea contains nitrogen.

(6) In a similar manner proceed to examine a few crystals of uric acid.

THE UREA.—The urea is made up of carbon, hydrogen, oxygen, and nitrogen, and its composition is represented by the formula $CO(NH_2)2$. It is a

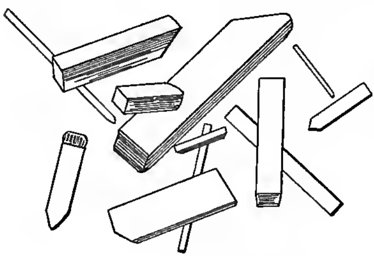


FIG. 90.—Crystals of urea.

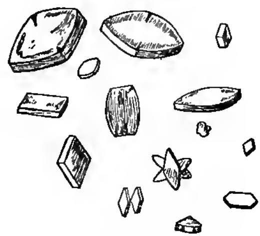


FIG. 91.—Crystals of uric acid.

crystallised body which is soluble in water and gives a neutral reaction. The urea in the urine is converted into carbonate of ammonia by the action of an organism. The amount of urea which leaves the body each day in the urine is $1\frac{1}{4}$ ounces, and the only variation depends upon an excess of proteins in the food; but in a man who ingests just enough of these food substances to repair the waste of the tissues, the urea will be a fixed quantity. Muscular exercise has no influence on the amount of urea which leaves the body. All the combined nitrogen which enters the body in the food leaves in the urea and uric acid. The urea is formed principally in the liver from the **creatine**, which

is a waste substance formed in the muscles and other parts of the body.

THE URIC ACID.—A small quantity of uric acid is found in urine (about 10 grains per day), but in birds it is the principal constituent of the nearly solid urine. It crystallises in plates or prisms (Fig. 91), and is soluble in water.

THE FORMATION OF URINE.—The substances in urine are separated from the blood, which passes through the kidneys, and the purest blood in the body is found in the renal vein. From the blood which passes through the glomeruli in the Malpighian capsules of the uriniferous tubules, water is filtered off, and the cells in the convoluted portions separate from the blood in the capillaries which surround them, urea, uric acid, inorganic salts, &c. The water as it passes along the tubule dissolves the solid materials and so forms urine. The urine enters the collecting tubules, and is discharged into the calyces in the pelvis of kidney. It passes from these structures down the ureter, and enters the bladder, where it is stored up until it is convenient to allow it to leave the body.

QUESTIONS FOR REVISION

1. What is the shape and general appearance of a kidney? Describe the structure of a kidney.
2. Give the position, appearance, and structure of the kidneys.
3. Describe the circulation of the blood through a kidney.
4. What is a ureter, and what important function does it perform?
5. Give an account of the position, shape, structure, and use of the bladder.
6. What is the most important substance, and, next to water, the most abundant substance present in urine?
7. What is urea? What chemical elements does it contain? Where does urea come from before it enters the urine?
8. How is urine formed, and what substances does it contain?

CHAPTER XX

THE NERVOUS SYSTEM

In very simple animals, such as the amœba, the whole of the body seems to be adapted to receive stimuli, but in the higher forms of life certain organs are specialised to act as a nervous system. In man the nervous system consists of (1) a brain and spinal cord, (2) the cranial and spinal nerves, and (3) a sympathetic chain of ganglia and nerves.

THE PROTECTION OF THE NERVOUS SYSTEM.—The brain is protected from injury by the bony walls of the cranium (p. 39), and the membranes which envelop it. The outer membrane is known as the **dura mater,** which lines the interior of the cranium, and is tough and strong. It is composed of fibrous connective tissue, and the arrangement of the bundles gives it strength and a certain amount of elasticity. The middle membrane, the **arachnoid membrane,** is similar in structure to the dura mater, but it is not so thick. The inner membrane is known as the **pia mater,** and it lines all the depressions of both brain and spinal cord. It is very thin, and consists of two layers, only the inner one being present in the brain. Blood-vessels come between the pia mater and arachnoid membrane in the brain, and in the space between the layers of the pia mater in the spinal cord.

The spinal cord is surrounded by the bony walls of the neural tube, and the arrangement of the vertebræ

and intervertebral discs of cartilage give the necessary protection. In addition, the dura mater lines the tube, and the arachnoid membrane and pia mater are present as in the brain, only there are two layers in the pia mater, between which numerous blood-vessels run.

Experiment 66.—Obtain from a butcher the head of a sheep, and with a saw remove a portion of the bony wall of the cranium. Note:—

(1) The thickness of the wall, and how the various bones interlock.

(2) The dura mater generally adheres to the under surface, and a piece can now be removed for examination. It is thick, tough, and strong.

(3) Remove a small piece of the pia mater which clings to the brain, and spread out on a slide in a drop of salt solution. Cover and examine. Look for the blood-vessels.

NERVOUS MATTER.—Both the brain and spinal cord is made up of a substance which is known as **nervous matter,** and which is supported by a tissue, the **neuroglia.** The former substance can be divided according to colour into **white** and **grey** matter. In the brain the grey matter is outside with scattered masses embedded in the white matter, but in the spinal cord the white matter is outside and the grey within.

The grey matter consists of **nerve cells** or **neurons** and their processes. Each neuron is made up of a large nucleus, which is surrounded by a quantity of protoplasm from which a number of processes or **dendrons** arise. These branch again to form **dendrites** (Fig. 92). From each neuron there arises a single process or **axon,** which does not branch until it ends as an end organ in a muscle fibre or in the skin. Such

a cell is said to be a multipolar neuron. The grey matter of the brain and spinal cord is built up of an immense number of multipolar neurons, which, even if they vary in size in different parts, still present the general structure described above. The neuroglia which supports the grey matter consists of cells and fibres which ramify between the neurons.

The white matter of both brain and spinal cord is made up of the numerous axons which arise from the

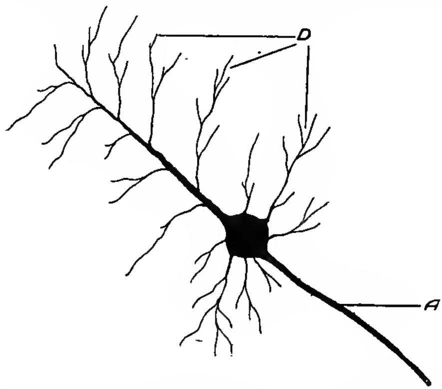


FIG. 92.—A neuron from spinal cord. *A.* axon; *D.* dendrites, the fine branches of the processes or dendrons.

neurons, and each one is covered with a soft fatty substance, the **medulla**, so that the white matter consists of **medullated nerve fibres**, but they are not covered with neurilemmas. These are supported by neuroglia, like the grey matter.

Experiment 67.—(1) Remove a very little of the grey matter from the sheep's brain, and spread out in a drop of salt solution. Examine with the high power, and look for **neurons**. Each neuron consists of a cell from which numerous processes arise. Try and make

out (i) the **dendrons,** which are branches which branch again to form **dendrites**; (ii) the axon or axis cylinder, which is the only branch of the neuron which does not branch at once; (iii) the large **nucleus.**

(2) Remove a little more of the grey matter, and stain in a little eosin in a watch-glass for five minutes. Mount in salt solution, and find the neurons. If the staining has been successful, the structure of the neurons will be well defined.

(3) Tease out a little of the white matter of the sheep's brain in a drop of salt solution. Examine, and look for medullated axons. Each axon is covered with a soft substance, which is divided into lengths by a number of depressions or **nodes.**

(4) Stain a little of the white matter in a drop of a 1 per cent. solution of osmic acid. The medulla stains black, and the axon stands out well defined.

Experiment 68.—(1) Lay bare one of the front limbs of a dead rabbit, and separate the muscles. Look for the brachial nerve, and follow it upwards to the cervical swelling where it originates. Trace its branches to the various structures in the limb, noting how it branches and ends in very fine nerves.

(2) In a similar manner remove the skin of one of the hind limbs, separate the muscles, and find the sciatic nerve. Follow the nerve upwards to the lumbar swelling where it originates, and downwards to the muscles of the limb.

THE STRUCTURE OF NERVES.—Most of the nerves in the body arise from the grey matter in the brain and spinal cord. From the brain originates twelve pairs of cranial nerves. These are distributed to the organs of the face, head, and a few organs of

the trunk. The spinal cord gives origin to 31 pairs of spinal nerves. These are distributed to the organs of the trunk, the skin, and muscles. Nerves can be recognised during the dissection of an animal as white-looking cords which frequently divide, and end in connection with the different structures examined.

A large nerve is surrounded by a sheath of connective tissue, which is known as the **epineurium,** and which con-

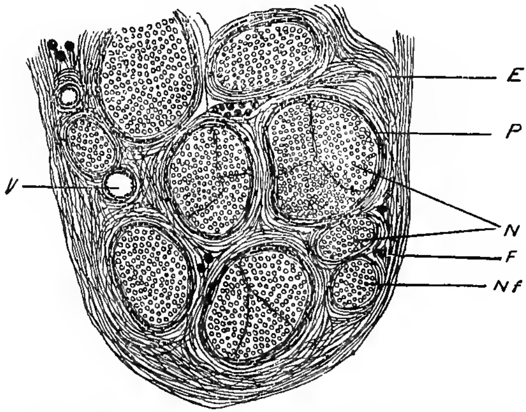


FIG. 93.—Transverse section of a portion of tibia nerve. *E.* epineurium; *P.* perineurium; *N.* nerve bundles; *N.f.* cut ends of nerve fibres within the nerve bundle; *F.* adipose tissue; *V.* blood-vessel.

tains blood-vessels and lymphatics for the nourishment of the nerve fibres. Inside the sheath there are a number of nerve bundles, each of which is surrounded by a sheath, the **perineurium.** The nerve fibres in the bundles are united by a fine connective tissue, the **endoneurium.**

Experiment 69.—(1) Remove a piece of the sciatic nerve from the rabbit, and lay it on a slide. Pass a pin through the end several times so as to separate

the fibres. Mount in a little salt solution and examine. Note (i) the nerve fibres; (ii) the **axon** or **axis cylinder,** which runs along the centre of the fibre; (iii) the **neurilemma,** which surrounds the nerve fibre; (iv) the **medulla,** which comes betweeen the neurilemma and axon; (v) the **nodes,** which are depressions into which the neurilemma dips, and the medulla is absent; (vi) the **nucleus** in each division between two nodes.

(2) Remove a similar piece, and place in a watch-

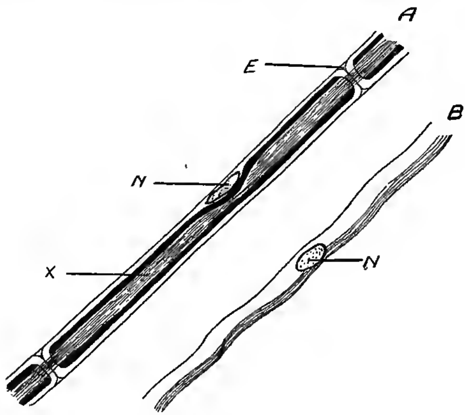


FIG. 94.—*A*, medullated nerve fibre. *E*, node; *N*, nucleus; *X*, axon. *B*, non-medullated nerve fibre. *N*, nucleus. (Magnified.)

glass which contains a little 1 per cent. solution of osmic acid. Tease and mount at the end of five minutes. Look for the medulla, which is stained a dark black, and for the structures enumerated above.

(3) If possible, examine a prepared transverse section of a nerve, and find: (i) the epineurium, which surrounds the nerve; (ii) the perineurium, which surrounds the nerve bundle; (iii) the endoneurium, which encloses the nerve fibres; (iv) the cut ends of the nerve

fibres (Fig. 93); (v) the blood-vessels and lymphatics which run in the epineurium, &c.

THE STRUCTURE OF NERVE FIBRES.—A large nerve trunk, such as the ulna or sciatic nerve, contains a number of nerve fibres which have the following structure: (i) The nerve fibre appears, when seen under a microscope, like a string of sausages. This is due to the **nodes** of Rauvier (Fig. 94). (ii) The nerve fibre is covered with a fine sheath, the **neurilemma,** which dips into the nodes. (iii) The **axon** or **axis cylinder,** which is continuous along the centre of the nerve fibre, and which is made up of very fine fibrils. (iv) The medulla, which is a fatty material, is absent at the nodes, and each internode contains a nucleus. A nerve fibre which contains a medulla is known as a **medullated nerve fibre.**

In addition to the medullated nerve fibres, a nerve contains a smaller number of fibres which consist of an axon and a fine sheath, the **axolemma.** Such a fibre is said to be **non-medullated.**

CLASSIFICATION OF NERVES. — The nerves may be classified according to function into two main classes, as—

Kinds of Nerve.	Carry Impulses from
Afferent or sensory .	The end organs in the skin, tongue, nose, eyes, and ears to the central nervous system.
Efferent or motor . .	The central nervous system to muscles, glands, and heart.

THE TERMINATION OF NERVE FIBRES.—The motor nerve fibres which are supplied to voluntary muscles end in structures which are known as **end plates.** Each one consists of a granular mass which belongs to the muscle fibre, the **sole** of the end plate, and the axon branches again and again to form a ramification which ends in connection with the above structure. The neurilemma unites with the sheath of the muscle fibre.

In involuntary muscles the non-medullated nerve fibres twine round the structures to form **plexuses,** and they end in connection with the muscle fibres, but the exact method is not fully understood.

The sensory nerve fibres end in connection with end organs in the skin, tongue, nose, eyes, and ears. The structure of these we shall consider in connection with the senses.

QUESTIONS FOR REVISION

(1) How is the central nervous system protected from injury?

(2) What is nervous matter, and how does the grey matter differ from the white matter?

(3) Describe the structure of a neuron.

(4) What does a nerve look like when seen with the naked eye? What is shown by the microscope to be its structure?

(5) Give a classification of nerves.

(6) How do nerve fibres end in (*a*) the skin, (*b*) muscles?

CHAPTER XXI

THE SPINAL CORD AND SYMPATHETIC SYSTEM

THE SPINAL CORD.—The spinal cord is about 18 inches in length; it commences at the **medulla oblongata** (spinal bulb), and ends in a filament, the **filum terminale,** at the level of the second lumbar vertebra. The filum terminale is surrounded by numerous nerve-roots, which form the **cauda equina.** The white matter is external, and completely surrounds the grey matter. The spinal cord possesses two well-defined swellings, one in the cervical and the other in the lumbar region. From the upper swelling arises the large nerve trunks which supply the upper limbs (the brachial nerves), and from the lower those which enter the legs (the sciatic nerves).

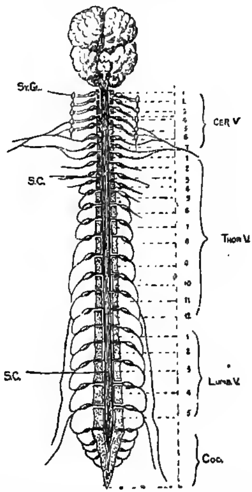


FIG. 95.—Diagram showing the relation of the brain, spinal cord, spinal nerves, and vertebræ. *Cer. V.* cervical vertebræ; *Thor. V.* thoracic vertebræ; *Lumb. V.* lumbar vertebræ; *Coc.* lower portion of vertebral column; *S.C.*, *S.C.* Spinal cord; *Sy. Gl.* sympathetic ganglia.

The cord is deeply divided down the anterior surface to form the anterior cleft, and in a similar manner there is a posterior cleft down the opposite surface. The

grey matter in such a section forms four horns (cornua); the two largest form the anterior, and the pointed ones the posterior horns. In the centre of the grey matter a small opening will be seen, the **central canal** of spinal cord, which is lined with ciliated cells and contains a little cerebro-spinal fluid. The white matter surrounds the horns of grey matter, and is far more abundant than the latter. The former consists of

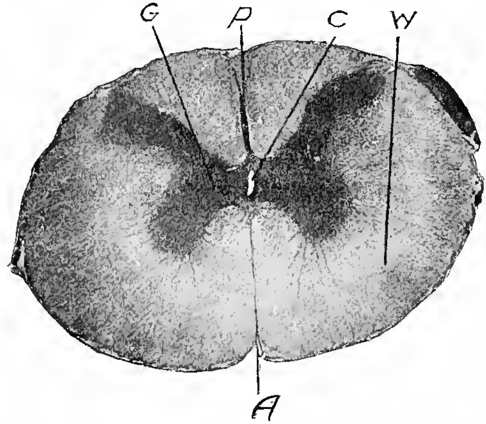


FIG. 96.—Transverse section of human spinal cord made in the cervical region. *A*, anterior fissure; *P*, posterior fissnre; *G*, grey matter showing horns; *W*, white matter; *C*, central canal of cord. (Photomicrograph by Flatters, Milborne & M'Kechnie.)

neurons and neuroglia, while the latter is made up of axons and neuroglia. There is a definite increase in the amount of white matter from the level of the second lumbar vertebra right to the spinal bulb, but the grey matter only increases in quantity in the cervical and lumbar swellings.

Experiment 70.—(1) Obtain from a butcher the spinal cord of a sheep. Cut across a piece with a

sharp knife, and examine the exposed surface with a hand-lens. Find (i) the pia mater, which contains blood-vessels; (ii) the pointed posterior horns of grey matter; (iii) the large rounded anterior horns; (iv) the central canal of the cord; (v) the posterior and anterior clefts or fissures; (vi) the white matter of the cord.

(2) If a prepared transverse section of the spinal cord is available, examine it, and make out the parts enumerated above (Fig. 96).

THE SPINAL NERVES.—Each half of the spinal cord is divided into three portions by grooves, viz. :—

$$\left.\begin{array}{l}\text{The posterior}\\ \text{The lateral}\\ \text{The anterior}\end{array}\right\}\text{ columns.}$$

Each spinal nerve is formed by the union of a pair of nerve roots; from the groove between the lateral and anterior columns arises an anterior root, and from near the groove between the lateral and posterior columns arises a posterior root. The two roots join to form the spinal nerve, and it leaves the neural tube by the intervertebral foramen.

On the posterior root before it joins the anterior root there is a small swelling, the **posterior ganglion.** This is surrounded by a capsule of connective tissue, and contains numerous neurons, each of which possesses a single process, which joins it by a **T**-piece. This is a **unipolar neuron** or nerve cell. The axons in the posterior root arise from the unipolar neurons in the posterior root-ganglion; these pass into the cord, and outwards to the end-organs in the skin. The axons in the anterior root arise from the neurons in the anterior horn of the grey matter of cord, and they pass outwards to end in muscles, &c.

In most cases each spinal nerve divides into three branches:—

(1) The **posterior branch,** which supplies the skin and muscles of the posterior surface of body.

(2) The **anterior** or **somatic branch,** which supplies the skin and muscles of the anterior surface of body.

(3) The **splanchnic branch,** which joins the sympathetic ganglia and viscera of trunk.

THE CLASSIFICATION OF THE SPINAL NERVES.—The spinal nerves can be arranged into

(1) Eight cervical nerves in the region of the neck.

(2) Twelve thoracic nerves in the region of the thorax.

(3) Five lumbar nerves in the region of the loins.

(4) Five sacral nerves in the region of the sacrum.

(5) One coccygeal nerve in the region of the coccyx.

NERVOUS IMPULSES.—If the end-organ in the skin is stimulated, there is set up what is called a nervous impulse, which passes along the axon of the nerve fibre to its neuron, and a sensation is produced. At present we do not fully understand what a nervous impulse is, but there is a change in the electrical condition of the axon when such an impulse passes along, and this has led some physiologists to consider that it is an electrical current which is set up when the end-organ is stimulated. On the other hand, it has been suggested that the movements of the molecules of the axon is the nervous impulse. This is all that can be said at present with regard to what a nervous impulse is.

FUNCTIONS OF SPINAL ROOTS.—The functions performed by the different roots of a spinal nerve can

be ascertained either by direct experiment or by post-mortem examination of the spinal cord or its roots after death due to accident. If the anterior root of a spinal nerve is cut across, the muscles which it supplies are paralysed, and this shows that the axon in the root brings impulses from their neurons to the muscle fibres. This is confirmed, for if a slight electric current is sent along the portion of the root connected to the muscle, it contracts.

If the posterior root is cut across, the portion of the skin which it supplies loses all sense of feeling, but if the end of the root connected to the spinal cord is stimulated, there is produced a sensation. Experiments of this kind demonstrate that the anterior or efferent root carries impulses from the central nervous system to the outlying parts of the body; while the posterior or afferent root brings impulses from the skin to the central nervous system.

This has been confirmed by medical cases, in which the patient could not move his leg, but could feel with his skin, and in other cases the skin has lost its sensibility, but the muscles retain the power of contracting. In the former case, post-mortem examination has shown that the anterior roots had degenerated; in the latter the posterior roots were in a similar condition.

Dr. Waller has discovered that if an axon is separated from its neuron it degenerates; this is due to the nucleus of the cell governing the nutrition of its different parts.

The method of tracing out the course and functions of the different nerves and parts of the spinal cord, based on the degeneracy of the axons when separated from their neurons, is named, after its discoverer, the **Wallerian method.** If a nerve is cut, it degenerates, but in time **regeneration** takes place, for the axons

connected with the neurons bud, forming new growths, which pass along the old neurilemmas until they unite with the end-organs in the skin and muscles. As far as our present knowledge goes, regeneration does not occur in the central nervous system.

REFLEX ACTIONS.—A reflex action is one which is not under the control of the will. A number of the movements of every-day life are reflex, such as walking, talking, eating, &c. At first, walking and talking are voluntary acts which are under the control of the will, but in time some portion of the nervous system becomes so accustomed to performing these actions that they are performed without the will being called into play, or they become **reflex**. The brainless frog can perform very complex reflex actions. If such a frog is suspended by a piece of cotton placed under the fore-limbs, and a toe on the hind-limb is squeezed, the legs move quickly to drive the intruder away. If a drop of very weak acid is placed on the skin of the ventral surface of trunk, the feet move to wipe it off. No such movement can take place when a pin is passed down the neural tube, for this destroys the spinal cord; this clearly demonstrates that the spinal cord can govern some reflex actions.

FUNCTIONS OF SPINAL CORD.—The spinal cord contains subsidiary vaso-motor centres; these can act in restoring vascular tone when the cord is broken, and they most likely act in a similar manner when it is perfect. Impulses pass from the legs and trunk up the cord to the brain, and from the brain to the lower portions of the body. If the cord is broken, the portion of the body below the break loses all power of voluntary movement and sensibility. The cord possesses the

power of performing reflex actions. If the cord is broken at the level of the twelfth thoracic vertebra the legs are paralysed, but if the sole of one foot is touched with a feather the legs are moved. This is due to the end-organs in the skin being stimulated, and the afferent fibres carry the impulse to the neurons in the portion of the cord below the break; these convey the impulses to the neurons in the anterior horns, which send them along their axons to the muscles, which contract, thus producing the movements observed.

THE SYMPATHETIC SYSTEM.—The sympathetic system consists of twenty-four pairs of ganglia and the nerves by which they are united. The ganglia lie in front and at the sides of the vertebral column, and the splanchnic branches of the spinal nerves join them. The ganglia contain nerve cells, and the axons which leave these are of the non-medullated kind. These are distributed to the viscera and blood-vessels. The ganglia consists of:—

(1) Three pairs of cervical ganglia in the neck region.

(2) Twelve pairs of thoracic ganglia in the thoracic region of trunk.

(3) Four pairs of lumbar ganglia in the lumbar region of trunk.

(4) Five pairs of sacral ganglia in the region of the sacrum.

THE FUNCTIONS OF THE SYMPATHETIC SYSTEM.—Numerous functions are performed by the sympathetic system, such as governing the movements of the viscera, dilation of pupil of eye, secretion of digestive fluids, excretion of sweat, and controlling size of small arteries (vaso-motor action). In addition to

the above functions the system helps to form the renal, pelvic, and hypogastric plexuses.

QUESTIONS FOR REVISION

1. Where does the spinal cord commence, and where does it end? What is the spinal cord made of, and how is it protected from injury?
2. What is the general structure of the spinal cord? Illustrate your answer by a cross section of the cord.
3. In what way are the spinal nerves connected with the spinal cord, and how does a spinal nerve branch?
4. Classify the spinal nerves.
5. What is a nervous impulse? If you saw one person who could move his arm but could not feel with his fingers, what parts would you suppose were injured?
6. Explain what is meant by a reflex action. Give some examples.
7. What are the functions of the nerve roots?
8. What are the functions of the spinal cord?
9. State the position, general structure, and functions of the sympathetic nervous system.
10. Explain what is the result of injury to the spinal cord (*a*) at the level of the bottom of the neck, (*b*) at the top of the neck, (*c*) at the level of the middle of the back.

CHAPTER XXII

THE BRAIN AND ITS FUNCTIONS

THE BRAIN.—The brain, like the spinal cord, is made up of white and grey matter, but the latter forms an external layer and scattered masses within the white. From the masses of grey matter arises the nerves of the brain. The brain consists of the following main portions:—

(1) The spinal bulb or medulla oblongata.

(2) The pons varolii; a bridge of fibres in front of the cerebellum.

(3) The cerebellum, which is deeply divided by a cleft.

(4) The cerebrum, which covers all the other parts, and is divided into right and left hemispheres.

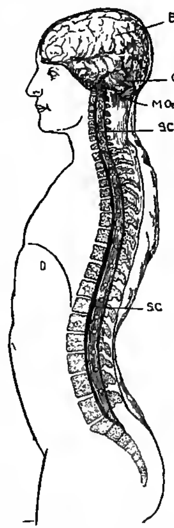


FIG. 97.—Diagram showing position of central nervous system. *B.* cerebrum; *Cr.* cerebellum; *M.Ob.* medulla oblongata; *S.C.*, *S.C.* spinal cord in neural tube; *D.* diaphragm.

THE MEDULLA OBLONGATA.—The medulla oblongata connects the spinal cord to the higher parts of the brain; it is about $1\frac{1}{2}$ inches in length, 1 inch wide, and $\frac{3}{4}$ of an inch in thickness. It is shaped like a pyramid, with the narrow end joining the cord, and the broad one is connected to the cerebellum. In structure it is somewhat similar to the spinal cord, but it contains more grey matter, and a cavity, which is known as the fourth ventricle.

THE FUNCTIONS OF THE MEDULLA OBLONGATA.—The spinal bulb performs numerous functions; the most important ones are:—

(1) It is the sole pathway along which impulses travel from the spinal cord to the higher centres in the brain, and from the higher centres in the brain to the spinal cord. If it is severed from the spinal cord,

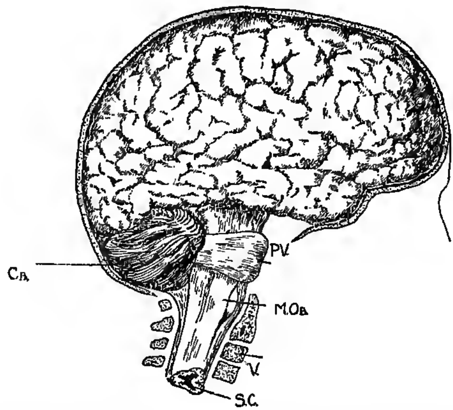


FIG. 98.—The brain as seen from the right side. *Cb.* cerebellum; *P. V.* pons varolii; *M.Ob.* medulla oblongata; *S.C.* spinal cord; *V.* upper cervical vertebræ.

the power of motion and sensation will be lost to the lower parts of the body.

(2) It contains a centre which governs respiration, the respiratory centre. This appears to be double, one part governing inspiration and the other expiration. If this centre is injured, death takes place; this is due to the stopping of respiration.

(3) It contains a cardiac centre which regulates the beat of the heart, but, unlike the respiratory centre, has nothing to do with the production of the rhythmical

movements, these being due to the peculiar cardiac muscle fibres of which the heart consists.

(4) The main vaso-motor centre is situated in the spinal bulb, and it is always sending out impulses which control the size of the small arteries.

(5) It contains a centre which controls swallowing.

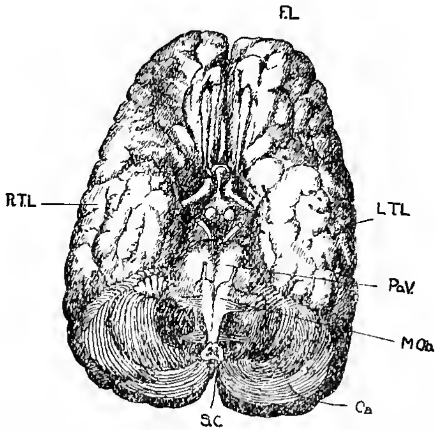


FIG. 99.—The brain as seen from below. *S.C.* spinal cord; *M.Ob.* medulla oblongata; *Po.V.* pons varolii; *Cb.* cerebellum; *R.T.L.* right temporal lobe; *L.T.L.* left temporal lobe; *F.L.* front lobe of cerebrum.

(6) It also contains a centre which governs the secretion of saliva.

It is quite evident, from a consideration of the functions performed by the spinal bulb, that injury to it may cause instant death through the arrest of respiration.

THE CEREBELLUM AND PONS VAROLII.—The cerebellum is about the size of a medium-sized apple, or is 4 inches wide, $2\frac{1}{2}$ inches deep, and 2 inches in thickness. A deep cleft separates it into right

and left portions, and these are united by a central worm-like body, *the vermiform process.* It is covered with grey matter, which is arranged in fine layers, and so folds that the surface area is increased, while its centre is made up of white matter which encloses small masses of grey matter. The pons varolii consists of a mass of fibres which join the two sides of the cerebellum.

THE FUNCTIONS OF THE CEREBELLUM.—The cerebellum co-ordinates the nervous impulses sent out by the higher centres of the brain, so that muscular movements are co-ordinated, and the ordinary processes of walking, &c., can be carried out. It is constantly being supplied with impulses from the skin, the eyes, the ears and muscles, which enable it to bring about co-ordination.

THE CEREBRUM.—The cerebrum is deeply divided by a fissure into right and left hemispheres, but they are united with a band of fibres, the **corpus callosum.** The hemispheres are covered with grey matter, and it passes into the convolutions. The quantity of grey matter will depend upon the number and depth of the convolutions, and in the highest form of brain (human brain) they are very numerous and deep. Beneath the outer cortex comes the white matter and several scattered masses of grey matter. The cerebrum also contains a pair of lateral ventricles or cavities which open into a small cavity, the third ventricle, and between the lateral ventricles there is a small cavity, the fifth ventricle. The ventricles and the membranes contain a fluid, the cerebro-spinal fluid, and this forms a kind of water-bed, which prevents shock.

THE FUNCTIONS OF THE CEREBRUM.—If the cerebrum is injured in a frog, it loses all power of feeling and power of voluntary movement. The cerebrum contains motor areas which govern the movements of legs and arms; a centre for hearing and vision. There is also a speech centre in the cerebrum, and centres for the sensation of smell and touch. In fact, it is the seat of the will and intelligence. The neurons in the various centres of the cerebrum generate and send out impulses, which produce most of the movements of the body.

THE BRAIN AND REFLEX ACTIONS.—The brain gives origin to numerous reflex actions. If a gun is discharged, the whole body starts at the noise produced; in this case the auditory nerve is the afferent nerve, and the motor nerves which govern the movements of the muscles are the efferent nerves. The pungent smell of ammonia causes the muscles of the face to contract; in this case the afferent nerve is the olfactory, and the facial nerve is the efferent. Talking and walking are carried out principally by reflex actions, and the whole of education depends very largely upon such actions.

THE CRANIAL NERVES.—The cranial nerves originate in masses of grey matter which are called nuclei, and they leave the surface of the brain. There are twelve pairs of cranial nerves; the first six leave the surface of the brain in front of, and the remainder from the spinal bulb. The following table gives the number, names, distribution, and functions of the cranial nerves.

No. of Nerve.	Name of Nerve.	Nerve of	Distribution of Nerve.	Function of Nerve.	Origin of Nerve.	Leaves Brain at
1	Olfactory.	Smell.	Mucous membrane of upper nasal chamber.	Special nerve of smell.	Olfactory bulb.	Front of cerebrum.
2	Optic.	Sight.	Retina of eye.	Special nerve of sight.	Optic centre.	Beneath cerebrum.
3	Motor oculi.	Muscles of eyeball.	Superior rectus, Inferior rectus, Inferior oblique, ciliary muscle, and sphincter muscle of iris.	Special efferent nerve of eyeball, change action of ciliary muscle, and size of pupil.	Grey matter in central brain near optic centre.	Pons.
4	Trochlear.	Muscles of eyeball.	Superior oblique muscle of eyeball.	Special efferent nerve of eyeball.	Near origin of 3rd nerve.	Pons.
5	Trigeminal.	Muscle of jaws, sensory nerve of tongue, jaws, &c.	Muscles of mastication, mucous membrane of jaw, lower nasal cavity, and front of tongue.	Efferent nerve of masticatory muscles, and afferent nerve of jaws, &c.	Double centre in grey matter of 4th ventricle.	Pons.

6	Abducens.	Muscles of eyeball.	External rectus muscle of eyeball.	Efferent nerve of external rectus of eyeball.	Grey matter near optic centre.	Pons.
7	Facial.	Expression of face.	Muscles of face.	Efferent nerves of muscles of face.	Grey matter below centre of 5th nerve.	Spinal bulb.
8	Auditory.	Hearing.	Internal ear.	Special nerve of hearing.	Several masses of grey matter.	Spinal bulb.
9	Glosso-pharyngeal.	Taste, &c.	Mucons membrane of back portion of tongue and muscles of pharynx.	Special nerve of taste.	Same centre as 10 and 12 nerves.	Spinal bnlb.
10	Vagus or Pneumo-gastric.	Numerous.	Heart, lungs, larynx, stomach, and liver.	Numerous functions.	Grey matter in floor of 4th ven-tricle.	Spinal bulb.
11	Spinal ac-cessory.	Muscles of neck.	Muscles of neck.	Motor nerve of muscles of neck.	From sides of spinal cord.	Spinal bulb.
12	Hypo-glossal.	Tongue.	Muscles of tongue.	Motor nerve of muscles of tongue and lower jaw.	Grey matter in floor of 4th ven-tricle.	Spinal bulb.

Experiment 71.—Place a dead rabbit with its dorsal surface upwards, and remove the skin and muscles from the head, neck, and back. Now with bone forceps or strong scissors remove carefully bit by bit the roof of the cranial cavity so as to expose the brain. In a similar manner remove the neural arches from the neural tube without injuring the spinal cord. Note on your dissection (1) the brain with its convolutions, and that the cerebrum is deeply divided into right and left hemispheres. (2) The spinal cord is a continuation of the brain, and commences at the medulla oblongata and ends at the filum terminale. (3) Find the cervical and lumbar swellings, and the roots of the spinal nerves which unite to form the spinal nerves. (4) Carefully remove the brain from the cranium, and find (*a*) the medulla oblongata, (*b*) cerebellum, (*c*) pons varolii, (*d*) cerebrum, (*e*) the cut or broken ends of the cranial nerves.

Experiment 72.—Obtain a sheep's head and remove the dorsal walls of cranium. Place the head with its exposed brain in a five per cent. solution of formalin. This will harden the brain, and at the end of about five weeks it will be possible to cut slices from it, thus exposing the various structures. (1) Carefully cut thin slices from the dorsal surface of the brain, noting the convolution of the cerebrum and the white matter beneath. (2) Follow a similar method with the other parts of the brain, illustrating with sketches the structures which are exposed during the dissection.

QUESTIONS FOR REVISION

1. Give a general account of the structure of the human brain?
2. How is the brain protected from injury, and nourished?
3. What important functions are performed by the medulla oblongata?

4. Why does death take place when the medulla oblongata is destroyed?

5. State the exact position of the cerebellum. What important function is performed by the cerebellum?

6. How would you proceed to dissect a sheep's brain so as to expose the principal structures?

7. Define ventricle, nervous matter, convolutions, and cortex.

8. Give some account of the functions performed by the cerebrum.

9. What are reflex actions? Describe some well-known reflex actions. Of what service are reflex actions?

10. Enumerate the names and general functions of the cranial nerves.

11. How would you proceed to dissect out the nervous system of a dead rabbit so as to expose the brain and spinal cord?

12. Write a short essay on the structure of the nervous system and its functions.

CHAPTER XXIII

SENSATIONS

MIND.—The intelligent principle in man is often described as mind, and this depends upon the action of the brain. Mind is a function of the brain, and is never found apart from nervous matter. The improvement of the mind is brought about by the education of the neurons in the brain, and these are brought in contact with external objects by means of a number of organs which are known as sensory organs. The young child has to learn to speak, and the constant repetition of a word, such as "mother," acts on the plastic brain, impulses are sent along nerves to the muscles which act on the vocal organs, and the child tries again and again to say "mother"; at last it succeeds. In the mind of the child the word mother is associated with the face and voice of its parent. In this way the neurons are educated, and a permanent record is stored in them.

All education depends upon impulses being received by the neurons, and during each day the various objects which are seen, felt, or tasted give rise to impressions. The stored-up impression is known as an **engram** (pronounced *ongram*), and the storing of these in the neurons creates in time the intellectual mind.

SENSATIONS.—The individual is constantly receiving from the outer world stimuli, and these give rise to what are known as sensations. The simplest mental operation with which we are acquainted is known

as a **sensation.** Before a sensation can be produced, several structures and conditions are necessary. These are:—

(1) A **stimulus** must reach an end-organ on the end of a nerve fibre. The stimulus may just be a pressure brought to bear on some portion of the skin, or a ray of light entering the eye.

(2) An **end-organ** to receive the stimulus. This may be in the skin, tongue, nose, eye, or ear, depending upon the kind of stimulus received by the organ.

(3) An **afferent nerve fibre** to carry the nervous impulse produced to the brain. These are the fibres mentioned in dealing with the two kinds of nerves (p. 237).

(4) A **nervous centre** in the brain to receive the appropriate impulse brought by the afferent fibre. The neurons are stimulated, and a mental process is set up which is known as a sensation.

It is no use for stimuli to act on the body unless there is present the appropriate nerve ending to receive it. Thus rays of light falling on the eye of a blind man will not fulfil the conditions enumerated above, nor will sound waves collected by the outer ear be of any service without the proper apparatus to bring it to the nerve of hearing.

The smallest stimulus which will produce a sensation can be said to be the lowest limit of sensibility. In a well-lighted room in which the source of light comes from 100 electric lamps, if one is turned off, the difference in the amount of light can be distinguished, but one out of 1000 lamps would not be distinguished. This has caused physiologists to define the lowest limit for light as $\frac{1}{100}$, for sound $\frac{1}{3}$, weight $\frac{1}{17}$, and temperature $\frac{1}{3}$.

PRECEPTIONS.—Psychologists have shown that sensations can be built up into preceptions. Each sensation, as we have seen, leaves an impression on the neurons, and an engram is stored up, but engrams build up what is known as **memory**. The smell of a rose gives rise to a pleasant sensation. The sight of the same rose gives sensations of colour, shape, and beauty. All these are built up into a **precept**, and we preceive that the rose possesses certain characters. From a number of these preceptions comes the conception that flowers are nice to look at, give off perfume, and possess different shapes.

EDUCATION.—All education is based on sensations, and the difference between a well-educated person and one of defective education is in the main one of the number of engrams stored up in the brain. Sensations are constantly being produced, and the retentive brain stores them up for future reference.

QUESTIONS FOR REVISION

1. What is meant by mind?
2. Define engram. How do engrams aid education?
3. What is meant by a sensation? What structures are necessary before a sensation can be produced?
4. Define stimulus, end-organ, nervous centre, preception, precept, conception.
5. Write a short account of what is meant by education.

CHAPTER XXIV

THE SKIN AND DIFFERENT SENSATIONS

THE SKIN.—In Chapter XVIII. we noticed that the skin consisted of two layers, the epidermis and dermis, and that the latter was thrown into folds which were known as **papillæ.** Each one contains blood-vessels, nerves, and sweat glands (p. 213). The sensitiveness of the skin varies greatly in different parts, for the tip of the long finger is much more sensitive than that of the short finger, while the skin of the back possesses very little of this important property. The sense of touch depends upon the number of nerve endings in a given area of the skin, and the closer these are placed the more quickly will the response be to the stimulus. We will now consider the way in which the afferent nerve fibres end in the skin.

THE NERVE ENDINGS IN THE SKIN.—(1) To the skin of nearly all parts of the body, afferent nerve fibres are distributed. They are of the medullated type, and form plexuses in the dermis just beneath the epidermis. From the plexuses non-medullated nerve fibres pass into the Malpighian layer of the epidermis, where they enter between the cells. This seems to be the common method for the ending of nerve fibres in the skin.

(2) In special parts of the skin, such as the under-surface of the fingers or toes, the lips, and eyelids, the nerves end in connection with **touch corpuscles.**

Each touch corpuscle is about the $\frac{1}{290}$ of an inch in length, and the $\frac{1}{800}$ of an inch wide. It is conical in shape, and the fibre appears to end in the midst of a number of cells.

(3) Bodies of various shapes and sizes have been observed in the skin, in which nerve fibres end. These are known as **pacinian corpuscles, end bulbs,** and **corpuscles of Herbst.** For a description of these, more advanced text-books must be consulted.

Experiment 73.—Insert on the point of a pair of drawing compasses two pieces of cork, and obtain a good scale of inches and fractions. Now proceed to examine the sensitiveness of different parts of the skin.

(1) Place the points of the compass the $\frac{1}{12}$ of an inch apart, and apply them to the tip of the long finger, cheek, wrist, &c., of another student who is blindfolded. Note results.

(2) Test the same parts with the points of compasses (i) the $\frac{1}{5}$, (ii) the $\frac{1}{8}$, (iii) the $\frac{1}{2}$ inch apart. Note results.

Experiment 74.—Obtain a set of weights, such as is used for a chemical balance, and proceed to discover the sensitiveness of the skin to pressure. Place different weights on various parts of the skin of another student who is blindfolded. Note the results obtained for pressure at the wrist, palm of hand, under skin of long finger, upper skin of fingers, back of hand, &c.

Experiment 75.—Fill a number of test-tubes with cold water, warm water, and hot water. Also obtain a piece of ice and a copper rod. Now discover the hot and cold spots in skin of wrist. This can be done by dipping the copper rod in the different kinds of water, and on the ice, and apply gently to the skin of

wrist at different points. Draw a diagram of the wrist, with the hot spots shown in red and the cold spots in blue.

LOCALISATION OF TOUCH.—The sensitiveness of the skin varies greatly, and the localisation of its acuteness can be ascertained with a pair of blunt compasses, a scale of inches, &c. (Experiment 73). The following table gives some of the best-known results of the acuteness of the sense of touch:—

Skin of	Distance apart of Points of Compasses in Fraction of Inch.	Results.
Tip of long finger .	$\frac{1}{12}$	Two points felt.
Under lip . . .	$\frac{1}{8}$	" "
Tip of nose . . .	$\frac{1}{4}$	" "
Back of hand . .	$1\frac{1}{8}$	" "
Back	2	" "

Webber's law of sensitiveness of the skin states "that the distance between the two points of the compasses depends upon the number of nerve endings which come between the points." The more numerous the nerve-endings in the skin, the nearer together the points of the compasses may be placed, and the keener the sense of touch.

THE TEMPERATURE SENSE.—The sensation of heat and cold differs in many important respects from other sensations. If a warm body is placed near the skin, we obtain a sensation of heat; this is probably due to special nerve endings in the skin. On the other hand, if a piece of ice is placed on the skin, the sensation of cold is perceived. The sensations of hot and cold last much longer than the sense of touch, but they develop much slower. The skin of the cheeks, lips, and eyelids

are especially sensitive to hot and cold objects, while the skin of legs and back do not respond so well to the stimulus of either hot or cold bodies.

THE PRESSURE SENSE.—The difference between a weight of 30 and 60 grains will be easily distinguished with the eyes closed, but one of 50 and 51 will be indistinguishable. It is the pressure of these different weights on the skin which enables us to distinguish one from the other. The **muscular** sense depends upon the nerve endings in tendons, and by this sense the differences between half and three-quarters of a hundredweight would be clearly recognised.

QUESTIONS FOR REVISION

1. Give a general account of the structure of the human skin, dwelling especially upon the nerve endings in the papillæ.
2. When you touch a body with your finger you can tell whether the body is rough or smooth ; why cannot you do this if the skin of the finger be injured or removed? In what part of the body is the sense of touch most acute, and in what parts least? How can you determine this accurately?
3. What is meant by the temperature sense?
4. How would you proceed to locate the hot and cold spots associated with the skin of the wrist?
5. Define pressure sense. How can the acuteness of the skin for pressure be tested?

CHAPTER XXV

THE TONGUE AND SENSE OF TASTE

THE TONGUE.—The tongue is covered with mucous membrane of the usual type, which is folded to form a number of **papillæ.** It contains numerous small goblet and much branched mucous glands, both of which form mucus. The papillæ can be divided into:—

Kind of Papillæ.	Distribution of.	Shape of.	Functions of.
Filiform.	The whole upper surface.	Tapering, and may branch.	Touch.
Fungiform.	Scattered over upper surface.	Shaped like a mushroom, and contain a few taste-beds.	Taste.
Circumvallate.	At the back of tongue, only eight or ten arranged in the form of an inverted V.	Like a castle with a moat round, and contain numerous taste-buds.	Taste.

TASTE-BUDS.—Each taste-bud is oval in shape, and consists of numerous closely-packed cells, the **gustatory cells,** the whole being enclosed with covering cells. The gustatory cells are narrow, elongated cells, and their lower ends are connected to nerve fibres.

A small opening leads into the taste-buds, and the upper ends of the gustatory cells come beneath this pore. The covering cells cover the contents of the taste-bud in a similar manner to the outer leaves of a bulb. The gustatory cells form the end-organs on the nerve fibres, which are distributed to the tongue and mouth. In addition to the taste-buds on the fungiform and circumvallate papillæ, they are found in the soft palate and epiglottis.

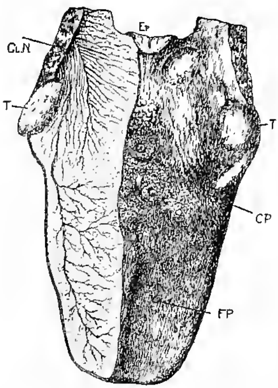


FIG. 100.—The human tongue. *Ep.* epiglottis; *T.T.* tonsils; *Gl.N.* glosso-pharyngeal nerve; *C.P.* circumvallate papillæ; *F.P.* filiform papillæ. One half of the tongue dissected to show distribution of nerve.

THE NERVES OF TONGUE.—The lingual branch of the fifth nerve is supplied to the front of the tongue, and a branch of the glosso-pharyngeal to the back portion. Thus the tongue does not possess a special nerve of taste, which is used exclusively for the carrying of impulses to the brain, for each of the nerves enumerated above perform other functions. The fibres of the branch of the glosso-pharyngeal end in connection with the gustatory cells.

Experiment 76.—(1) Examine the tongue of a dead rabbit, and note the aggregation of papillæ near the back of the upper surface. They form two prominent masses and contain taste-buds. Remove the tongue and cut across the papillæ. Use a hand-lens, and try and find the taste-buds.

(2) If possible, examine a prepared section of the

human tongue, and look for the taste-buds on either the fungiform or circumvallate papillæ. Show in a sketch the covering cells, end-cells, and ostiole or pore of bud.

Experiment 77.—(1) Prepare the following solutions: (*a*) A 10 per cent. solution of common salt, by dissolving 10 parts of salt in 90 of water. (*b*) Dissolve 5 parts of quinine in 95 of water. (*c*) Dissolve 10 parts of

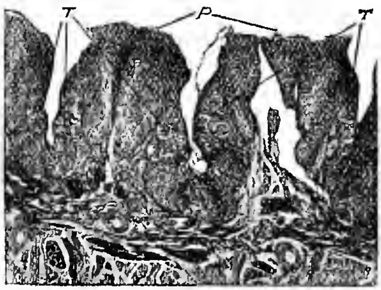


FIG. 101.—A vertical section through circumvallate papillæ of tongue. *P.* circumvallate papillæ; *T.* taste-buds. (Photomicrograph by Flatters, Milborne & M'Kechnie.)

sugar in 90 of water. (*d*) Mix 1 part of acetic acid in 99 of water.

(2) Wash out the mouth, and with a clean camel-hair brush apply a drop of the salt solution to different parts of the tongue. In what part of the tongue is the taste of salt best appreciated?

(3) Proceed in a similar manner to find out the part of the tongue where bitter tastes are best appreciated, using the 5 per cent. solution of quinine.

(4) Wipe the surface of the tongue with a clean handkerchief, and place a crystal of sugar upon it. No sweet taste will be experienced until the secretions of the tongue moisten it and dissolve the sugar. This

shows that substances must be soluble to enter the taste-buds.

(5) Now apply drops of the solution of sugar to the upper surface of the tongue, and discover which portion is most sensitive to sweet tastes.

(6) Now, using the acetic acid solution, try and discover which portion of the tongue responds the most readily to sour or acid tastes.

NOTE.—A separate brush must be provided for each student, and this should be carefully washed in a stream of running water between each experiment.

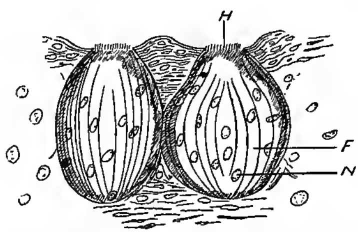


FIG. 102.—Taste-buds from tongue of rabbit. *F.* fusiform covering cells; *N.* nuclei of gustatory cells; *H.* hair-like ends of gustatory cells.

TASTES. — From a strictly physiological point of view, there are only four true tastes; these are **sweet, bitter, sour,** and **saline.**

(1) The sweet tastes can be best appreciated by the tip of the tongue. A child often touches its sugar-stick with the tip of its tongue. Of course, all parts will respond to sweet tastes, but the portion of the tongue which acts the quickest is the one mentioned above.

(2) Bitter tastes can be best appreciated by the back portion of the tongue, where the circumvallate papillæ are grouped together.

(3) Sour or acid tastes can be distinguished the quickest by the sides of the tongue.

(4) Saline tastes can be distinguished by all parts of the tongue in about equal proportions.

All the other so-called tastes are flavours or odours, and they act on the organ of smell. The old-fashioned

method of nipping the nose when medicine was taken had many advantages, for it meant swallowing or choking, and the odours in the nasty stuff did not reach the upper nasal chambers. The sense of smell can be improved by practice, but neither alcohol nor tobacco should be used. It is said that 1 part of sulphuric acid in 1000 of water can be detected by a well-trained tongue.

QUESTIONS FOR REVISION

1. Describe the structure of the human tongue, dwelling especially upon the mucous membrane.
2. Enumerate the different kinds of papillæ found associated with the tongue.
3. What is a taste-bud? Of what use are taste-buds?
4. Give a set of experiments which demonstrate the various tastes associated with the taste-buds.
5. Enumerate the tastes which the end-organs in the taste-buds can distinguish.
6. What do you know of the nerves which end in the tongue?

CHAPTER XXVI

THE NOSE AND SENSE OF SMELL

THE sense of smell depends upon (1) the end-organs in the upper nasal chambers, (2) the olfactory nerve, (3) the olfactory centre in the brain. The end-organs can be stimulated with the scent-particles, which diffuse into the upper nasal chambers. These set up impulses which pass along the nerve of smell to the neurons in the olfactory centre, where they give rise to the sensations of smell.

THE NOSE.—The nose consists of cartilage and bone, and it is covered with skin. It is lined with mucous membrane, and a septum divides the right side from the left. The upper wall is formed of the cribriform plate of the ethmoid bone. This is perforated with a number of small holes, through which the fibres of the olfactory nerve pass to the mucous membrane; while the lower wall consists of the hard palate which separates it from the mouth, and the sides are formed by the peculiar scroll-like turbinated bones. The nose is well supplied with blood-vessels, and is a very vascular organ.

THE RESPIRATORY MUCOUS MEMBRANE.—The lower nasal cavities are lined with ciliated respiratory mucous membrane, the structure of which was described in connection with the chapter on respiration (p. 190). It contains small unicellular goblet glands, and very much branched mucous glands, which secrete

mucus. It is supplied with fibres from the fifth cranial nerve.

THE OLFACTORY MUCOUS MEMBRANE.—The upper nasal chambers are lined with thick yellow olfactory mucous membrane, and the fibres of the olfactory, or first pair of cranial nerves, end in its epithelium. It consists of two distinct kinds of cells, one with broad upper ends and irregular outlines, the **supporting cells,**

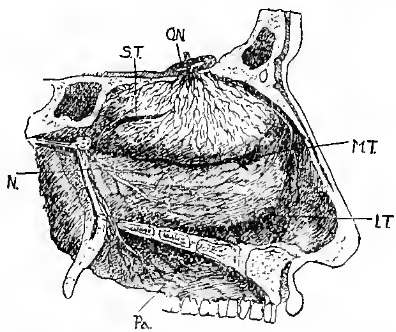


FIG. 103—Vertical section through the left nasal cavity. *Pa.* palate; *I.T.* the inferior, *M.T.* the middle, and *S.T.* the superior turbinal bones; *O.N.* the olfactory nerve; *N.* the fibres of the fifth nerve, which supply the lower or respiratory mucous membrane.

and those with a small rounded cell-body with a large nucleus and two pointed ends, the **olfactory rod cells.** The upper end of the rod cell stands just above the supporting cells, while the lower one is connected with a fibre of the olfactory nerve. These rod cells form the end-organs of the nerve of smell, and are supported by the other cells of the epithelium (Fig. 104).

THE NERVE OF SMELL.—The olfactory lobes of the brain contain neurons, and the fibres from these

reach the rod cells. The fibres are of the non-medullated kind, and pass through the perforations in the cribriform plate, thus reaching the end-organs with which they are connected. In addition to the above, which is the true nerve of smell, fibres of the fifth cranial nerve reach the respiratory mucous membrane.

Experiment 78.—Ask a butcher to cut a fresh sheep's head into two vertical halves through the nose.

(1) Make out the characters of the walls, noting the cribriform plate, hard palate, and turbinated bones.

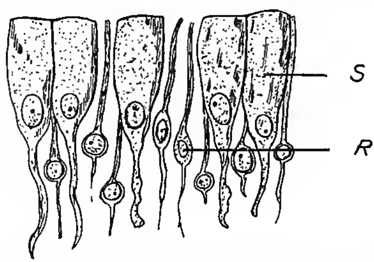


FIG. 104.—A group of cells from olfactory mucous membrane. *S.* supporting cell. *R.* olfactory rod cell with nerve fibre attached to lower process.

Trace out the region of (i) the respiratory mucous membrane, (ii) the yellow olfactory mucous membrane.

(2) Find the nerve fibres which are supplied to the nose.

(3) Now with careful dissection make out the course of, and distribution of, the olfactory nerve.

(4) If possible, examine a prepared section through the nose, and find the supporting and rod cells.

Experiment 79.—(1) Eat a piece of onion, holding the nose so that no scent particles can enter. Under these conditions the onion is nearly without taste.

(2) Smell of lavender, and note that "**sniffling**" produces the sensation of smell much better than during ordinary breathing. This is owing to the sniffling drawing the air out of the upper nasal chambers, the **odorous particles** rushing in to take the place of the air withdrawn, when they come in contact with the rod cells, which are stimulated.

THE SENSE OF SMELL.—The rod cells are stimulated by either gaseous or small solid particles which touch their upper processes. The changed conditions of the cells set up impulses which travel along the axons to their neurons, where the sensation of smell arises. It is said that the sense of smell can be improved with practice, and as small a quantity of musk as the $\frac{3}{100,000,000}$ of a grain can be distinguished with a good nose. To improve this sense it is important to notice that pure air should be breathed, and that the indulgence in smoking and alcoholic beverages are not conducive to this end.

QUESTIONS FOR REVISION

1. Describe in general terms the structure of the nose.
2. How does the olfactory mucous membrane differ from the respiratory mucous membrane?
3. With what part of the nose do we smell? What is the nerve by which we smell? From what part of the brain does it start, and how does it reach the nose? Why does closing the nostrils do away with certain so-called tastes?
4. Give an account of the olfactory rod and supporting cells.
5. Why do we smell better when we snift, and why do bad colds generally prevent the sensation of smell?
6. Explain how the sense of smell and taste may be improved.

CHAPTER XXVII

THE EYE AND SENSE OF SIGHT

THE eye is a highly specialised organ which brings the rays of light to a focus on the end-organs in the retina. Sight depends upon (1) the apparatus which receives the rays of light which are reflected from an object, and brings them to a focus on the retina; (2) the end-organs in the retina which transform the rays of light into nervous impulses, which pass along; (3) the fibres of the optic nerve to; (4) the optic centre in the brain. Defects in the action of any of the parts enumerated above either lead to defective sight or to blindness.

THE EYE.—The eye is protected by (1) the bony walls of its orbit; (2) eyelids; (3) eyelashes; (4) eyebrows. In studying the structure of the face, we noticed the orbits or eye-sockets, and that their walls were strong, offering protection to their contents. The upper and lower eyelids also play an important part in preventing injury to the front of the eye. Each eyelid contains a plate of strong tissue, which forms a **tarsus**, and it is covered with skin. From the edges of the eyelids hairs protrude, and help to prevent dust from entering the eye. The eyelids can be moved so as to cover the front of the eye; this is done by the contraction of a circular muscle, which is composed of striated fibres, and is placed under the skin. A branch of the facial nerve (7th C.N.) brings impulses

to the muscle, and its contraction moves the upper eyelid downwards, at the same time the lower one is drawn slightly upwards, thus closing the eye. The upper eyelid is elevated by the action of another muscle which is fixed to the tarsus (the superior levator), and a branch of the third nerve governs any movement it may make. The winking of the eyelids, which takes place at regular intervals of time, or about

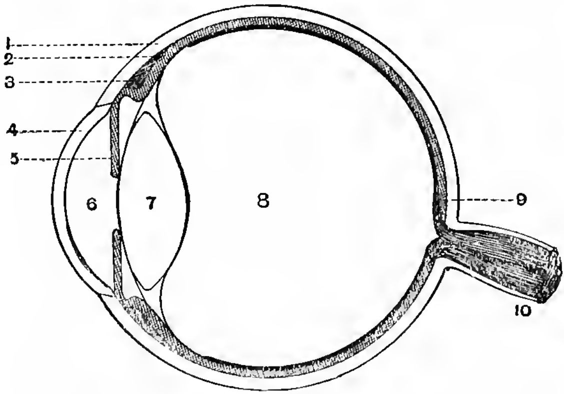


FIG. 105.—Diagram of eye. 1, sclerotic coat; 2, choroid coat; 3, ciliary process; 4, cornea; 5, iris; 6, anterior chamber, which contains the aqueous humour; 7, crystalline lens; 8, posterior chamber, which contains the vitreous humour; 9, retina; 10, optic nerve.

each two minutes, are reflex, and aid in keeping the front of the eyeball moist.

The eyebrow prevents rain and sweat from passing from the forehead into the eye.

THE CONTENTS OF THE ORBIT.—The eyelid is lined with a membrane which is known as the **conjunctiva**, and which is connected to the eyeball so as to close the cavity of the orbit. Sebaceous glands are present in the eyelid, and their secretions help to

moisten the eyeball. In the outer corner of the orbit there is a large gland, which is known as the **lachrymal gland,** which secretes tears. The tears consist of water which contains not more than 1 per cent. of solids, of which common salt is the most abundant. Tears may be secreted in such abundance that the **lachrymal duct** on the nasal side of the orbit and which opens into the nose is unable to carry

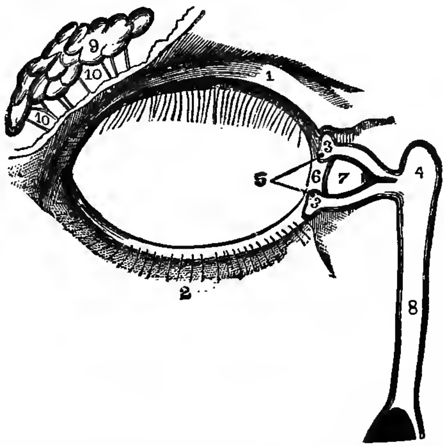


FIG. 106.—Lachrymal gland and duct of right eye. 1, upper eyelid; 2, lower eyelid; 3, 3, canaliculi; 4, lachrymal sac; 5, openings of canaliculi; 6, rudiment of third eyelid; 7, caruncle; 8, lachrymal duct; 9, lachrymal gland with its small ducts, 10.

them away, when they roll down the cheeks—when the person is said to cry. Tears help to keep the eyeball moist and cool, and help to remove particles of dust which may enter beneath the eyelids.

The eye rests on a layer of adipose tissue, which forms a soft bed. The sunken appearance of the eyes after a long illness is due to the fat from the tissue being removed, and not to any alteration of the eyes.

The orbit contains a number of muscles which are fixed to the back of its bony walls and to the sclerotic coat of the eye. These are :—

(1) The superior rectus or straight muscle, which on contraction raises the eye upwards.

(2) The inferior rectus muscle, which on contraction pulls the eye downwards.

(3) The external rectus muscle, which on contraction moves the eye outwards.

(4) The internal rectus muscle, which on contraction moves the eye inwards towards the nose.

(5) The superior oblique or cross muscle, which is fixed beneath the superior rectus, and passes through a tendon which is fixed to the top of orbit; this rotates the eyeball slightly inwards, when it contracts.

(6) The inferior oblique, which is inserted near the inferior rectus, and can rotate the eye a little in the opposite direction to the superior oblique. The muscles are composed of striated fibres, and receive most of the 3rd, 4th, and 6th cranial nerves.

In addition to the structures enumerated above, the orbit also contains blood-vessels, which pierce the eyeball and supply blood for its nutrition, while the ciliary nerve enters the eyeball.

DISSECTION OF SHEEP'S EYE AND EXPERIMENTS

Experiment 80.—Obtain from a butcher a few sheep's eyes, and proceed to dissect them so as to ascertain the structure of the eyeball.

(1) Measure the size of the eyeball. It is about 1 inch in diameter, and may be covered with fat and muscle. (i) Remove the fat from the surface of the eyeball, and find the attachment of the muscles

(p. 275). (ii) Carefully clear the optic nerve at the back of the eyeball, and note that it does not enter at the centre, but slightly on the nasal side. (iii) Turn the eye over so that the cornea is uppermost. Note its shape and that of the pupil. The pupil is oblong with rounded corners. (iv) Make out the **sclerotic coat,** and note that it is strong, tough, and opaque. It covers about $\frac{5}{6}$ of the eyeball. (v) Trace out the cornea, which is transparent, and its surface has a

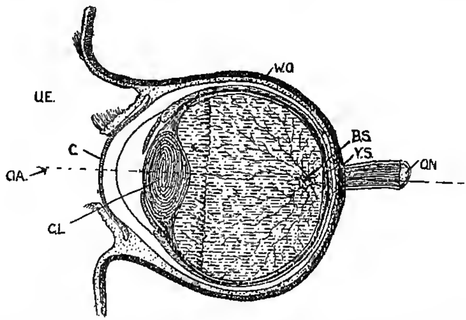


FIG. 107.—Vertical section of left eye. *U.E.* upper eyelid; *W.O.* wall of orbit; *C.* cornea; *C.L.* crystalline lens; *B.S.* blind spot; *Y.S.* yellow spot; *O.N.* optic nerve, which pierces the eyeball at *B.S.* on the nasal side of the optic axis, *O.A.*

different curvature to the sclerotic. It forms about $\frac{1}{6}$ of the outer coat of the eye.

(2) Place the eye in a dish of water, and cut into two equal halves through the cornea. (i) Float out the second or **choroid coat,** which lines the back portion of the eyeball up to the sclerotic. It is pigmented, and forms in front near the lens a number of processes, the **ciliary processes.** These terminate near the margin of the lens. (ii) Remove the lens, and find in front the **iris,** which is a continuation of the choroid, thus completing the second coat of eyeball.

The iris is made up of plain muscle, connective tissue, and contains blood-vessels. (iii) Try and trace out the position of the suspensory ligament which supports the lens. (iv) Note the shape of the crystalline lens. Hold it in front of the eye. This can be done by passing a pin through the rim. *Objects* seen through the lens are **inverted**. Place the lens on a piece of printed paper; the lens magnifies. (v) Examine the vitreous humour. It is like jelly, and slightly magnifies objects. (vi) Float out the retina, which comes in front of the choroid coat and up to the vitreous humour. It is a very delicate membrane, and is connected to the optic nerve and choroid. (vii) Find the place where the optic nerve pierces the sclerotic coat, and note its position. Try and find the blood-vessels which run along the centre of the optic nerve.

(3) Bisect another eye into two equal halves so as to obtain front and back halves. Examine these, and make out the different parts.

Experiment 81.—Obtain a cod's head from a fish-dealer. Remove with a pair of strong scissors the bones which surround the right eye. Note (i) the eyeball, which is covered with a transparent membrane; (ii) the optic nerve, which can be traced to the optic lobes in brain; (iii) the muscles, and their arrangement.

Experiment 82.—(1) Obtain a chalk-box, and remove one end; replace this with a piece of ground glass. Bore a hole the size of a shilling in the other end of the box.

(2) Hold the box, and either look at the window or the gas-flame; an image will be seen on the ground-glass screen. This shows that the image of an object

will fall on the retina in a similar manner to that on the glass screen.

(3) If possible, set up a camera, and focus some object so that the image appears sharp on the screen; note, it is inverted. Alter the focus, and the image is no longer sharp, but blurred. This shows that for an image to be sharp it must be focused. In the

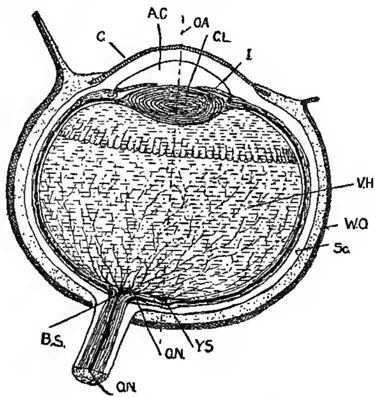


FIG. 108.—Horizontal section of right eye. *O.N.*, *O.N.* optic nerve; *B.S.* blind spot; *Y.S.* yellow spot in optic axis, *O.A.*; *V.H.* vitreous humour in posterior chamber; *C.L.* crystalline lens; *I.* iris; *A.C.* anterior chamber with aqueous humour; *C.* cornea; *Sc.* sclerotic coat; *W.O.* wall of orbit.

eye the change in the shape of the lens plays the same part as the racking of the lens outwards or inwards does in the camera.

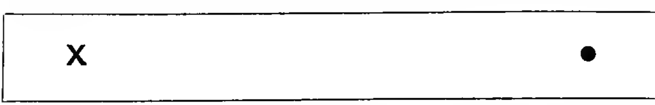
(4) Remove a portion of the sclerotic coat from the back of a fresh eye, and place the eye in a tube made of black paper. Now look at the gas-flame or other object; the image is inverted. Thus the crystalline lens inverts objects in a similar way to the lens in a camera.

Experiment 83.—(1) Hold a candle near the face of a watch, and note that three images can be seen.

(2) Stand in front of a looking-glass in a dark room, and note that **three images** of the candle flame can be seen in the cornea of the eye. (i) One image is bright and upright; this comes from the front of cornea. (ii) Another image is also upright, but not so bright as (i); this comes from the front of lens. (iii) The other image is dim, rather smaller than the others, and **inverted**; this comes from the back of the crystalline lens.

(2) Try and look at your finger and a distant object at the same time without altering the position of the eyes. Either the finger or the distant object will be blurred. Place two burette stands two yards apart on a table but in a direct line, sit in a chair and look at them. It is impossible to see both stands clearly at the same instant. This shows that there has to be a change in the eyes when looking from a distant to a near object; this change is known as **accommodation.**

Experiment 84.—(1) Construct on a sheet of paper the figure shown below. Hold the paper at arms'



length. (i) Close the left eye, and look at the **X**; both the cross and spot will be seen. (ii) Keep the eye on the cross, and slowly bring the paper nearer; the spot **disappears.** The image has moved on to the optic nerve, which is insensible to light. (iii) Bring the paper nearer to the eye; the image reappears.

(2) Turn the paper over so that the cross occupies

the position which the spot did in the last experiment. Proceed as before, only close the right eye; the spot disappears again. This is due to the optic nerve not being stimulated with the rays of light. **This experiment proves that you have a blind spot in each of your own eyes.**

THE STRUCTURE OF THE EYEBALL

The eyeball is about one inch in diameter, and consists of a number of coverings which have to do with the protection and nutrition of the retina. These we will now proceed to study.

THE SCLEROTIC COAT.—The white covering which envelops $\frac{5}{6}$ of the eyeball is known as the **sclerotic coat**, and its firmness helps to retain the shape of the eye. It is replaced in front with a transparent membrane, the **cornea**, which forms $\frac{1}{6}$ of the outer covering. The sclerotic contains a few blood-vessels, and an abundant supply of lymphatics. On the other hand, the cornea is entirely nourished with the lymph, and there is an entire absence of blood-vessels. The ciliary nerve supplies fibres to the outer coat.

THE CHOROID COAT.—The choroid coat is connected to the sclerotic at the point where the optic nerve enters the eyeball, and at the junction of cornea with that coat. In other parts it is somewhat loosely united with fibres of connective tissue. It contains pigment, and this helps to regulate the amount of light which falls on the retina, for it absorbs the rays of light. The choroid forms a series of **ciliary processes** near

the lens, and is continued in front of the lens to form the **iris**.

THE IRIS.—The iris is composed of connective tissue, blood-vessels, and contains pigment. It is made up of two layers of unstriped muscle, and around the pupil it forms a sphincter muscle which on contraction reduces its size. The iris is firmly connected to the sclerotic, and contains dark pigment in nearly all persons.

THE LENS.—The crystalline lens, which is fixed just behind the iris, is supported by the suspensory ligament. It is biconvex, but the front is more curved than the back, and it is very elastic; this property enables it to change its shape. At the junction of the lens and cornea a series of muscles are found, the **ciliary muscles**, which act on the suspensory ligament.

The lens is transparent, and because of its refractory power, it inverts the rays of light which pass through it.

THE HUMOURS.—Between the cornea and iris a watery fluid is present, the **aqueous humour**, and it consists of water which contains about one per cent. of solids. The function of this fluid is to keep the cornea in shape.

Between the crystalline lens and the retina there is a jelly-like substance, the **vitreous humour**, which is surrounded by a delicate membrane, the **hyaloid membrane**.

THE OPTIC NERVE.—The optic nerve is a process of the brain, and it is covered with layers of similar

structure to the membranes of that organ. It contains about 500,000 nerve fibres of the medullated type, but without neurilemmæ. The coverings unite with the sclerotic coat when the optic nerve enters the eyeball. In the centre of the nerve there is a small artery, which supplies blood for the nourishment of the elements in the retina.

THE RETINA.—The retina lines the back three-fourths of the eyeball, and during life is always in contact with the vitreous humour. It is the sensitive layer which responds to the stimulation of light and contains the nerve endings on the fibres of the optic nerve. These are known as **rods** and **cones.** The place where the optic nerve enters the retina is insensible to light, and is known as the **blind spot.** It does not contain rods nor cones, and shows that nerve fibres are insensible to the action of light. The **yellow spot** or **macula lutea,** which is a small depression in the optic centre of retina, is very sensitive to light, and contains numerous cones. In the very centre of the macula lutea there is a second depression, the **fovea centralis,** and it contains some 7000 cones. The elements in the yellow spot are far more sensitive to light than any other parts of the retina; this is probably due to the rays falling nearly directly upon them, and not having to pass through the other elements which are present in the retina.

THE PHYSIOLOGY OF THE EYE

LIGHT AND THE EYE.—From the practical work done, and from a consideration of the structure of the eye, we have noticed that light can enter the eyeball

and reach the retina. The course of the rays of light through the structures of the eyeball are:—

Rays of light
↓
Cornea
↓
Aqueous humour
↓
Pupil
↓
Crystalline lens
↓
Vitreous humour
↓
Retina.

The rays of light are bent or refracted in passing through the lens, and to such an extent that the image is completely *inverted* (Experiments 80 and 82).

Experiment 85.—(1) Obtain a wedge of glass and look at an object with it in a slanting position. The object seems to be in a different position to what it actually occupies. This is due to the dense glass refracting the rays of light.

(2) If a prism is available, allow a beam of light from a candle to pass through it and fall upon a screen. The beam of light is bent towards the base.

(3) If a similar prism can be obtained, place them base to base. The beams of light which pass through the prisms cross each other. The lens acts in a similar manner to a pair of prisms.

ACCOMMODATION.—We noticed in performing Experiments 82–3 that for the image to be sharp and distinct on the camera-screen, it was necessary to have the lens in a certain position, and the movement of the lens in either direction destroyed the sharpness of the image. When the light reflected from an object falls on the retina so that the image appears sharp and

distinct, it is in focus. If it is moved in either direction, certain changes take place in the eye before a distinct image is produced. This adjustment of the eye is known as **accommodation.**

The eye is generally adapted to view distant objects, and when a near object is examined, two changes take place in the eye: (1) the pupil contracts, and (2) the lens changes its shape. The pupil acts in a similar manner to the iris-diaphragm of a microscope, and it cuts off the more external rays of light. For more distant objects the pupil dilates once more. The contraction of the pupil may also help to support the lens during its change of form.

The front surface of the lens becomes more convex during accommodation. This is due to the contraction of the ciliary muscle, which is connected to the suspensory ligament and to the ciliary processes. It thus comes between the movable ciliary processes and suspensory ligament. On contraction, the ciliary muscle pulls the ciliary processes forward. This decreases the pressure of the suspensory ligament on the lens, and its elasticity comes into play, and its anterior surface becomes *more convex*. In looking from a near to a distant object, the relaxation of the ciliary muscle increases the pull of the suspensory ligament, and the front of the lens becomes *less convex*.

THE PUPIL.—The pupil regulates the amount of light which enters the eye. On entering a brightly-lighted room the ciliary nerve brings impulses from the optic centre to the iris, and the sphincter muscles contract. This reduces the amount of light which falls on the retina. This is a reflex action of a plain muscle. The afferent nerve is the optic nerve, and the efferent the ciliary nerve. The reverse of this takes place when

a person steps from a brightly-lighted room into darkness, and as the change in the pupil takes place, more light falls on the retina. Thus the iris performs three useful functions, viz. its contraction (1) supports the lens, (2) cuts off the external rays of light, (3) regulates the amount of light which enters the eye.

DEFECTIVE SIGHT.—Defective sight may be due to the shape of the eye and to defects of accommodation. The different kinds of sight are enumerated below:—

(1) The **normal** or **emmetropic eye** is, of course, the best; it possesses an indefinite accommodation for distant objects, and for near ones it varies from 10 to 12 centimetres.

(2) The **short-sighted** or **myopic eye** is much too long from back to front, and the image of an object a few feet away is brought to a focus **in front of the retina** in the vitreous humour. The range of accommodation is much less than with the normal eye, and for a near object varies from 5 to 6 centimetres, *i.e.* the object will be distinctly seen when held within that distance from the eye. The far limit varies, but in no case is it very great. Short-sight can be remedied by using concave glasses.

(3) The **long-sighted** or **hypermetropic eye** is much too short from back to front, so that the image of even a very distinct object is brought to a focus **behind the retina.** In such an eye there is no distinct accommodation, and the position of near vision will be a little distance from the cornea. Long-sight can be remedied by wearing convex glasses.

(4) In old age there is great difficulty in seeing near objects, and such an eye is said to be **presbyopic.** It resembles long-sight, but may differ from it in having good accommodation. In all cases of old sight much

can be done by wearing spectacles; these should be changed every few years.

CARE OF THE EYES.—The care of the eyes is of great importance, and every child should be taught the following:—

(1) Do not read between lights or when the light is dim. This has a tendency to produce strain, and will in time produce short-sight.

(2) Do not read very **small print** nor defective print. This acts in a similar way to **No. 1.**

(3) Do not read too long at once, and occasionally rest the eyes by closing them or looking off the book.

(4) Do not allow very bright light to fall directly on the eye, but in reading let it shine on the book and turn your back to the light.

(5) Do not smoke cigarettes, as the smoke from the paper as well as the tobacco injures the sight, and never smoke to excess. In the case of smokers they should find out how much tobacco can be used without injuring the eyes, and never exceed that amount.

In all cases of serious defect of the eye go to a specialist, and obtain the best advice obtainable, for new eyes cannot be bought like new teeth.

QUESTIONS FOR REVISION

1. What is the eye? Of what service is the eye?
2. Give an account of the action of the eyelids, eyelashes, and eyebrows. How are the eyelids moved?
3. What are tears? How are tears produced? Of what service are tears?
4. How and by what means are the eyes moved?
5. Describe the structure of the eye.
6. What is meant, in speaking of vision, by the "blind spot," and how can its presence be demonstrated? What conclusions concerning the nature of sight can be drawn from the existence of the blind spot?

7. What muscles are attached to the eyeballs? What movements of the eyeball are brought about by the contractions of these muscles?

8. Of what service is the iris and crystalline lens?

9. How do the fibres of the optic nerve end in the retina?

10. Explain how an image is brought to a focus on the retina, and under what conditions the image may be blurred or indistinct.

11. Describe the structure of the iris? State the changes in the iris which determine the size of the pupil, and why the pupil widens and narrows according to the amount of light which enters the eye.

12. How does the yellow spot differ from the blind spot?

13. Through what structures does a ray of light pass before it reaches the retina?

14. What is meant by accommodation? How is accommodation produced?

15. Explain how defective sight may be produced, and how it can be remedied.

CHAPTER XXVIII

THE EAR AND SENSE OF HEARING

THE sense of hearing depends upon (1) the apparatus which collects and conducts the sound waves to the nerve of hearing, and (2) the auditory centre in the brain. For just as we see or feel with the brain, so hearing depends upon the auditory neurons being stimulated by impulses set up in the auditory nerves. The apparatus which connects the external world with the neurons is known as the **ear.** This can be divided into three parts, viz. the external ear, middle ear, and internal ear. The structure of these we will now consider.

THE EXTERNAL EAR.—The outer or external ear consists of an expanded portion, the **pinna,** and the **auditory canal** or **meatus.** The pinna can be easily bent, and is composed of cartilage which is covered with skin. It encloses a central hollow which is known as the **concha,** and from which the auditory canal or meatus rises to the **membrane tympani,** which separates it from the middle ear. The external portion of this passage consists of cartilage, and the internal of bone. It is lined with skin, and this also covers the membrane tympani. From the skin, hairs protrude, and it contains **wax glands,** which secrete the **ear-wax.** The function of the external ear is to collect the sound waves and conduct them to the drum or tympanic membrane. If the ear-wax becomes too abundant or hard, it may prevent the passage of the sound waves, and cause deafness.

THE MIDDLE EAR.—The middle ear is a cavity hollowed out of the temporal bone, and which is lined with mucous membrane. From this cavity a cylindrical tube, dilated at both ends, the **Eustachian tube**, opens into the pharynx. This is made of bone and cartilage and lined with mucous membrane, which is connected with that of the pharynx. The cavity is

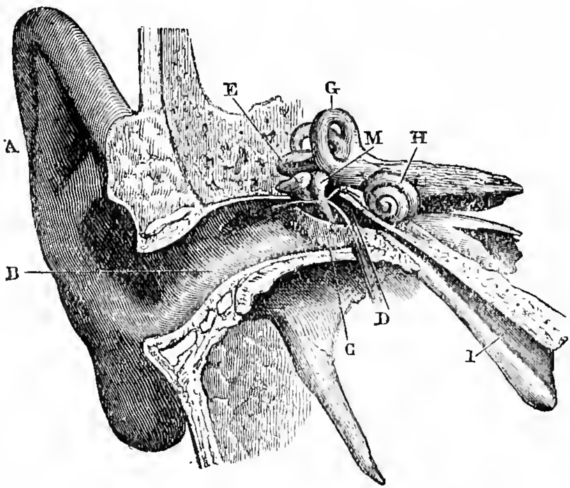


FIG. 109.—Diagrammatic section through the right ear. *A*, pinna of ear; *B*, auditory passage or canal; *C*, tympanic membrane; *D*, cavity of middle ear; *E*, incus; *M*, malleus; *G*, semicircular canals; *H*, cochlea; *I*, Eustachian tube.

separated from the external meatus by the tympanic membrane, and from the internal ear by bone and two pieces of membrane, one oval in shape, the **fenestra ovalis**, and the other round, the **fenestra rotunda.**

The cavity also contains a series of three small bones which are known as **ossicles**, and which conduct the sound waves across the middle ear. On the inner side

of the membrane tympani there is fixed a hammer-shaped bone, the **malleus.** It is attached by its long handle from the upper edge of the membrane to the centre, and one of its processes is united to a muscle; the other is inserted into a cavity in the side of the middle ear.

The second ossicle is known as the anvil bone or **incus.** It is shaped like a blacksmith's anvil, and its head possesses a well-defined surface for articulation with the malleus. One of its processes — the short

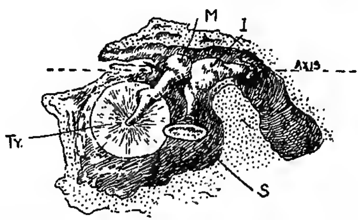


FIG. 110.—Diagram to show position of ossicles in middle ear. *Ty.* tympanic membrane; *M.* malleus; *I.* incus; *S.* stapes.

one—is expanded into a surface for union with the stapes.

The third ossicle is known as the stirrup bone or **stapes.** It is shaped like a stirrup, and its single process articulates with the incus. The broad portion of the stapes is united with the fenestra ovalis. Thus the cavity of the middle ear is bridged from the tympanic membrane to fenestra ovalis by means of the ossicles; for the malleus passes on the sound waves to the incus, which in turn transmits them to the stapes. The membranes, which fill in the openings in the bony walls, and the ossicles are covered with mucous membrane.

The Eustachian tube equalises the pressure in the middle ear, for the slightest movement of the tympanic

membrane or fenestra ovalis changes its pressure, and either air enters or leaves by this tube.

If the tympanic membrane is broken down, or the ossicles are disarranged, or the Eustachian tube is plugged up with mucus, deafness results.

THE INTERNAL EAR.—The internal ear consists of two portions, an outer, with bony walls, which forms the **osseous labyrinth**, and an inner, the **membranous labyrinth** (Fig. 112). The former is composed of a series of passages hollowed out of the temporal bone, the shape of which closely follows that of the latter. The openings in its walls are filled in with the fenestra

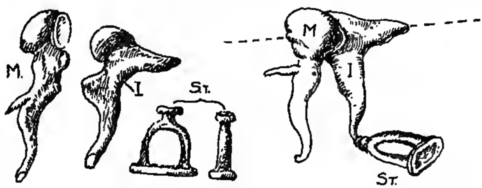


FIG. 111.—Diagram showing position and shape of ossicles. *M.* malleus; *I.* incus; *St.* stapes.

ovalis and fenestra rotunda. The function of the fenestra rotunda seems to be to equalise the pressure in the internal ear. Between the osseous and membranous labyrinth there is a fluid which is known as **perilymph.**

The membranous labyrinth consists of (1) three semicircular canals, (2) a cochlea, and (3) a vestibule. The semicircular canals are arranged in three planes—one horizontal, and the other two at right angles, but in vertical planes. Each one contains a fluid, the **endolymph,** in which small particles of lime, the **otoliths**, are embedded, and it is lined with a peculiar epithelium. Its cavity is continuous with the opening in the cochlea

and vestibula. The cochlea is shaped like the shell of the snail, and it contains the **organ of Corti.** The vestibula is formed by the dilated portions of the semicircular canals. The membranous labyrinth is moored to the sides of the osseous labyrinth by strong cords.

The auditory nerve, the eighth cranial nerve, enters

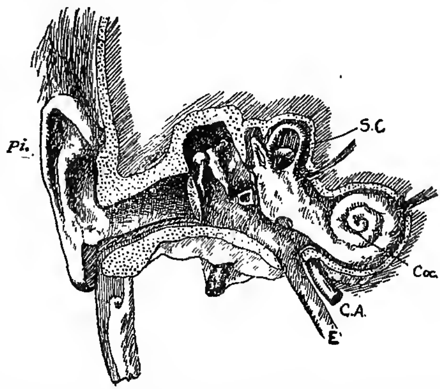


FIG. 112.—Diagram showing position and relation of the external, middle, and internal ears. *Pi.* pinna of ear; *E.* Eustachian tube; *C.A.* carotid artery; *S.C.* semicircular canals; *Coc.* cochlea.

the inner ear at the junction of vestibula and cochlea, and is distributed to its epithelium.

THE AUDITORY EPITHELIUM.—The whole of the interior of the membranous labyrinth is lined with epithelium, but the cells in the ampulla are columnar in shape, and possess processes which are known as **hair-cells** (Fig. 113). The base of the hair-cells are connected with the fibres of the auditory nerve, and they form end-organs.

DISSECTION OF EAR

Experiment 86.—(1) Obtain from a butcher a sheep's head, and find the bulba, which is wedged in between the squamosal and maxilla. Remove it, and note the opening of the auditory meatus, in which the membranous tympani is fixed.

(2) Open. Find the ossicles and Eustachian tube.

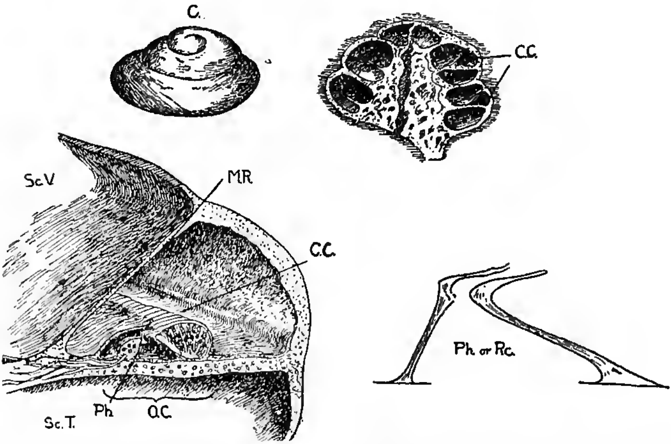


FIG. 113.—Diagrams of various parts of inner ear. *C.* external view of cochlea; *C.C.* section of cochlea showing vestibuli; *Sc.V.* scala vestibuli; *Sc.T.* scala tympani; *M.R.* membrane of Reissner; *C.C.* canalis cochlearis; *O.C.* organ of Corti; *Ph.* labium tympani or rods of Corti (hair-cells).

Experiment 87.—If possible, obtain a dogfish or head of skate, and proceed in the following manner to expose the auditory organ:—

(1) Remove with a knife the posterior portion of the skull on the left side, so as to expose the ear, which corresponds to the internal ear of a mammal. Note the three semicircular canals which can be seen through

the cartilaginous covering. Remove the cartilage with a sharp knife, and fully expose the different parts of the auditory organ.

(2) Trace the three positions of the membranous semicircular canals which open at both ends into the ampulla. They are (i) the horizontal; (ii) the anterior vertical; (iii) the posterior vertical. Sketch.

(3) Find the ampulla, vestibula, and auditory nerve.

(4) Remove the auditory organs, and preserve in methylated spirits.

Experiment 88.—(1) Fill the ears with cotton wool, and try and hear the sound of a vibrating tuning-fork. It will either be indistinct or not heard.

(2) Now place the handle of the vibrating tuning-fork to the bones of the head. The sound is heard distinctly, for the sound passes along the bones of the head to the internal ear.

(3) Remove the cotton wool, and place the ear to the end of a table. Get another student to give a sharp blow to the other end of the table. The sound will be heard. The sound waves pass through the wood to the external ear, and through the ossicles to the internal ear.

SOUND AND HEARING

SOUND.—The sound waves are produced by the action of vibrating bodies, such as bells, tuning-forks, &c. The waves travel in circles around the vibrating body, and travel at the rate of about 1100 feet per second in air. In water they travel over 4000 feet per second, in wood 17,000. The range of hearing varies from waves produced by 16 vibrations per second to as many as 38,000 per second.

HEARING.—The sound waves are collected by the pinna of the ear, and pass along the auditory meatus to the tympanic membrane, which vibrates. This sets in motion the ossicles which act on the fenestra ovalis, and the vibration is passed to the perilymph. The perilymph communicates its motion to the membranous labyrinth, and the otoliths in the jelly-like endolymph come in contact with the hair-cells. These are stimulated, and a nervous impulse passes along the fibres of the auditory nerve to the auditory centre in the brain, *and we hear.* This is shown below:—

Sound waves in air
↓
Membrane tympani
↓
Ossicles
↓
Fenestra ovalis
↓
Perilymph
↓
Membranous labyrinth
↓
Endolymph and otoliths
↓
Hair-cells
↓
Fibres of auditory nerve
↓
Auditory centre in the brain
↓
Sensation of hearing.

THE SEMICIRCULAR CANALS.—The action of the endolymph in the semicircular canals is to enable us to judge position, for it acts on the sensitive epithelium. The semicircular canals, as we have seen, are placed in the three planes of space, and in whatever position the head is placed the brain is able to distinguish it. In addition, they have to do with the

co-ordination of movements, for if they are injured, staggering is the result.

AUDITORY SENSATIONS.—These even take place when the tympanum is destroyed, and are probably set up in the auditory centre or in the hair-cells. Nearly every one suffers from recurrent auditory sensations. These may be due to having heard exciting music, speeches, or cries. One often starts up from sleep, thinking that a well-known or loving voice is calling. This is due to the auditory centre reproducing a recurrent sensation.

ATTENTION TO THE EARS.—Deafness may be due to the ear-wax, which accumulates, becoming hard, and prevents the sound waves from reaching the tympanum. This *must not* be removed with a pin, needle, nor hair-pin, for these may injure the tympanum and cause permanent deafness. It can be remedied in the following way. Drop into the ear a little warm glycerine on going to bed; repeat this for three consecutive evenings. Instruct a friend to syringe out the ear with warm water; in most cases this will remove the wax. If this should not be successful, consult a medical man. If the deafness arises from the Eustachian tube, also consult a doctor, and if a child suffers from runnings from the ears. In the latter case there is a considerable amount of danger, for the internal ear is only separated from the brain by a thin bone, and the pressure of the matter may break this and press on that delicate organ, doing irreparable injury to it.

QUESTIONS FOR REVISION

1. How are sound waves produced and brought to the nerve of hearing?
2. What is ear-wax, and how is it secreted?

3. Describe in general terms the structure of the ear.
4. Describe the position, shape, arrangement, and functions of the ossicles in the middle ear.
5. State the position, structure, and function of the Eustachian tube.
6. Describe the shape, position, and probable function of the semicircular canals.

INDEX

C

D

E

F

G

H

I

J

K

L

M

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